5G Business Case:

Operator Motivations for 5G Investment for Mobile and Fixed Wireless in the U.S. and Europe

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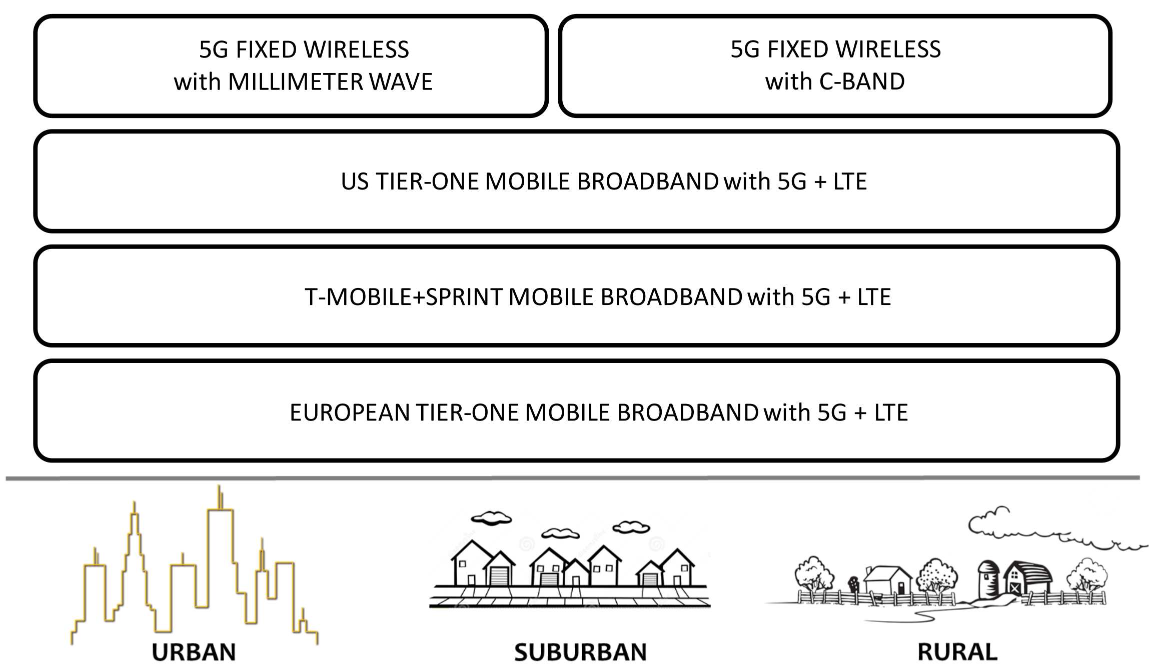
1. INTRODUCTION

In our last year's report on 5G Business Case, we examined three major use cases for 5G based on the early market trends in North America. They were: 1) 5G fixed wireless access; 2) enhanced mobile broadband; and 3) mobile plus video bundle. Our examination of these scenarios highlights that 5G with a combination of massive MIMO antenna technology and new spectrum in the C-band (3-4 GHz) and millimeter wave (24-40 GHz) offer lower cost per GB of delivering mobile data.

In this year's report, we take a deeper dive into the 5G fixed wireless case by taking a closer look at delivering fixed wireless services using the millimeter wave in urban environment (largely based on Verizon's 5G Home fixed wireless service launch in a few select markets this year) and 5G fixed wireless service using the C-band in rural environment. In addition, we examine a leading North American mobile operator and the hypothetical "New T-Mobile" with combined assets of T-Mobile and Sprint to see how they might deploy 5G across the different urban morphology based on estimated demand projections. Furthermore, we examine a European tier-one operator to examine why 5G investment in Europe lags other developed markets in North America and Asia-Pacific. In all, we examine these scenarios and corresponding business cases to highlight why the operators are investing in 5G and where they may deploy 5G infrastructure.



Source: Mobile Experts

Figure 1. 5G Business Cases Explored in This Report

2. Business Case 1: Fixed Wireless with 5G Millimeter-Wave

After years of technology development, 5G millimeter wave has become a reality. Verizon's 5G fixed wireless service recently launched in late 2018 is a case study of this feat. The service marketed as 5G *Home* is currently available in a few select markets including Sacramento, Houston, Los Angeles, and Indianapolis. It is priced at $70 per month for "standalone" fixed wireless offering or $50 per month "bundled" price if the subscriber also has a Verizon wireless data plan. According to Verizon, the service offers "typical speeds around 300 Mbps and, depending on your location, maximum speeds up to 940 Mbps."[1] The offered speed and pricing reveal a lot about Verizon's thinking and choices that it has made in balancing the capabilities and limitations of today's 5G millimeter wave technology and economics behind it.

Competitive Context of 5G Fixed Wireless in the USA

One of the questions that we are often asked is whether 5G fixed wireless can compete against dominant wireline broadband technologies such as cable and fiber. This strategic question infers additional questions, such as:

1. Can 5G fixed wireless offer competitive service at high-speed tiers?
2. Can it achieve low-cost economics to compete on price?
3. Which market segment is it most applicable? Where is its niche?

Based on Verizon's commercial service launch, the answers to the first and second questions appear to be "yes" to both. Verizon's 5G *Home* is competitive with comparable offerings from the major cable operators (see below). The price/performance of Verizon's 5G fixed wireless offering of "300 Mbps typical speed" at $70 monthly pricing is on par with cable operators' comparable offerings (i.e., Internet offerings of 200-250 Mbps at $65-$79 standalone pricing without bundle discounts). In fact, one might argue that Verizon's 5G fixed wireless service is priced at a discount considering that its super offering (i.e., Verizon's 300 Mbps is better than Comcast's 250 Mbps) is slightly cheaper than Comcast's "no term agreement" pricing of $79.

[1] Verizon 5G Home FAQ's (https://www.verizonwireless.com/support/5g-home-faqs/)

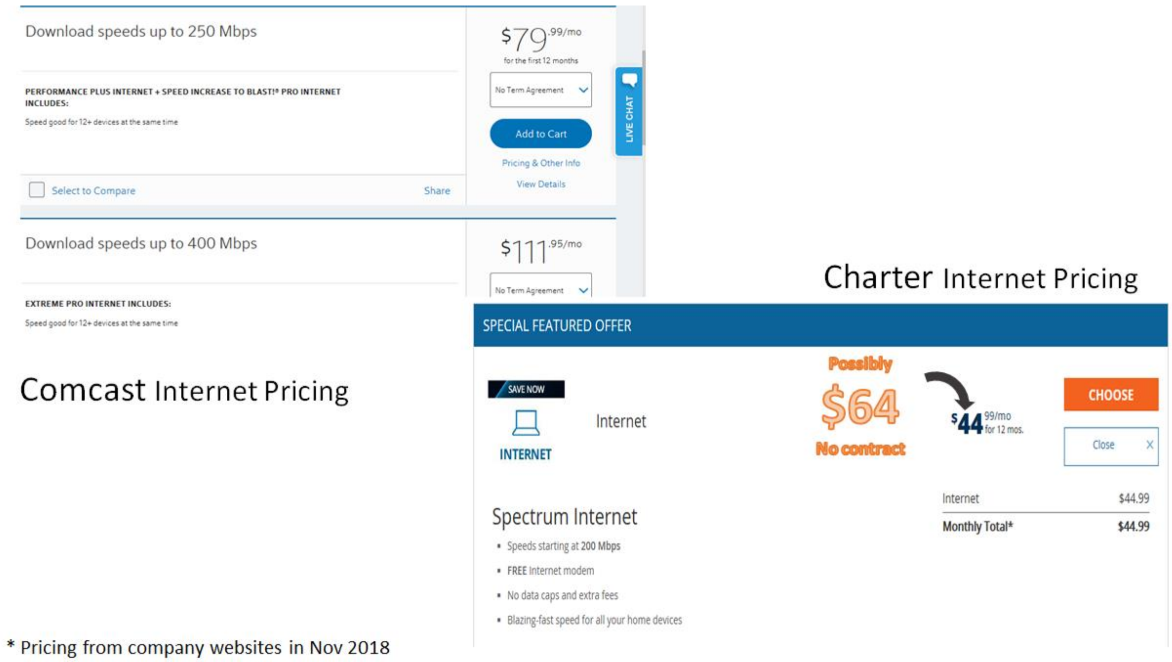
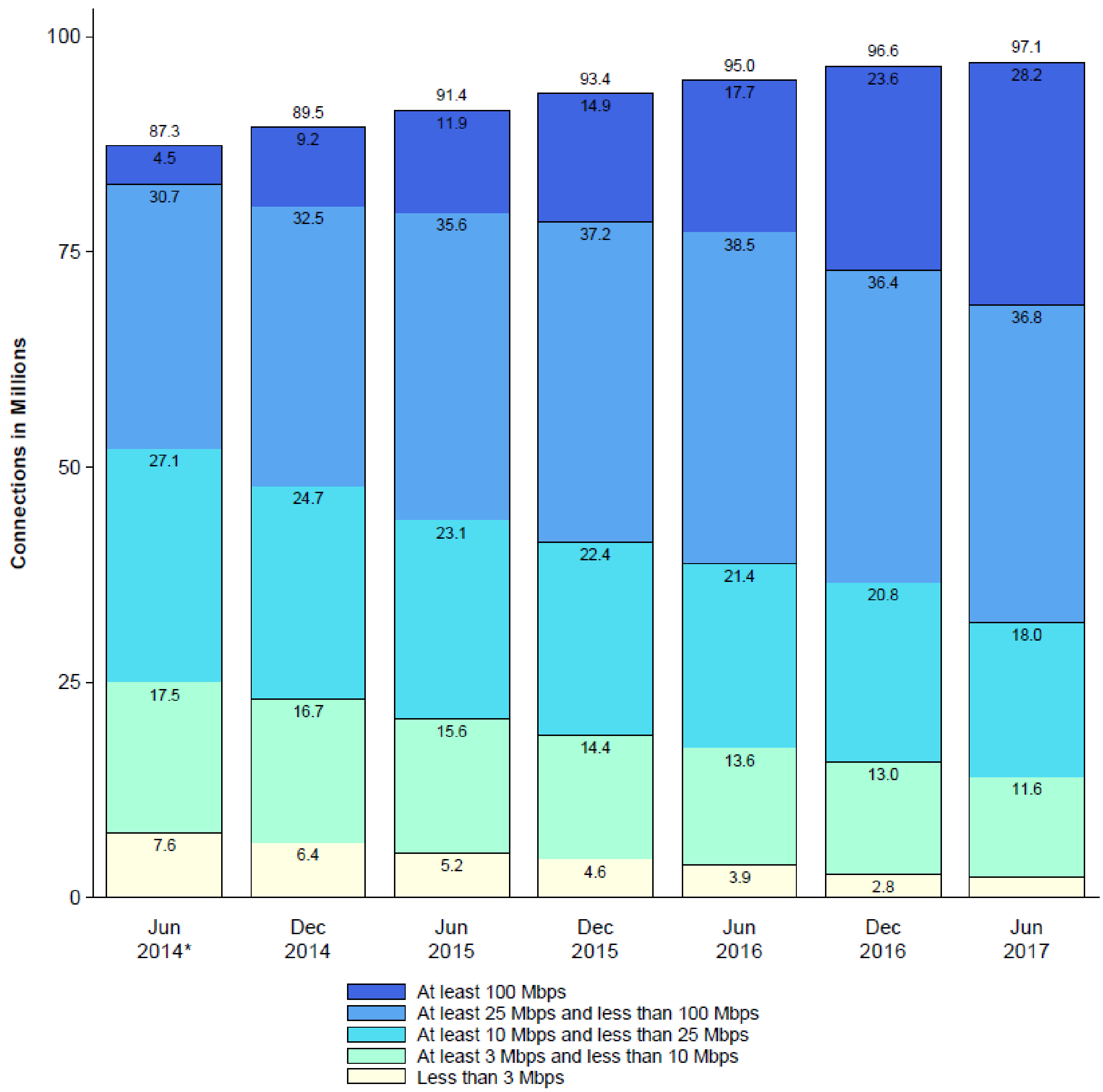


Figure 2. Cable operators' 200Mbps+ Internet offerings at $65-80 monthly pricing

As for the third question around market fit, as we will see in the next couple of sections, the 5G fixed wireless service based on the millimeter wave spectrum can achieve favorable economics with reasonable expectation around market penetration in high home density areas. While Verizon has announced commercial availability of 5G fixed wireless in several cities, we believe the company will seek high-density areas within those markets to achieve high market penetration.

According to the FCC, about 30% of American broadband households have 100 Mbps or greater fixed broadband connections as of June 2017, rising from 5% just three years prior.[2] No doubt, the trend towards higher speed broadband connections will continue to accelerate as the broadband demand continues to grow as more devices are connected and people spend more time online. Verizon's decision to target high-speed tier (i.e., 300 Mbps typical speed) is a reflection of where the market is heading.

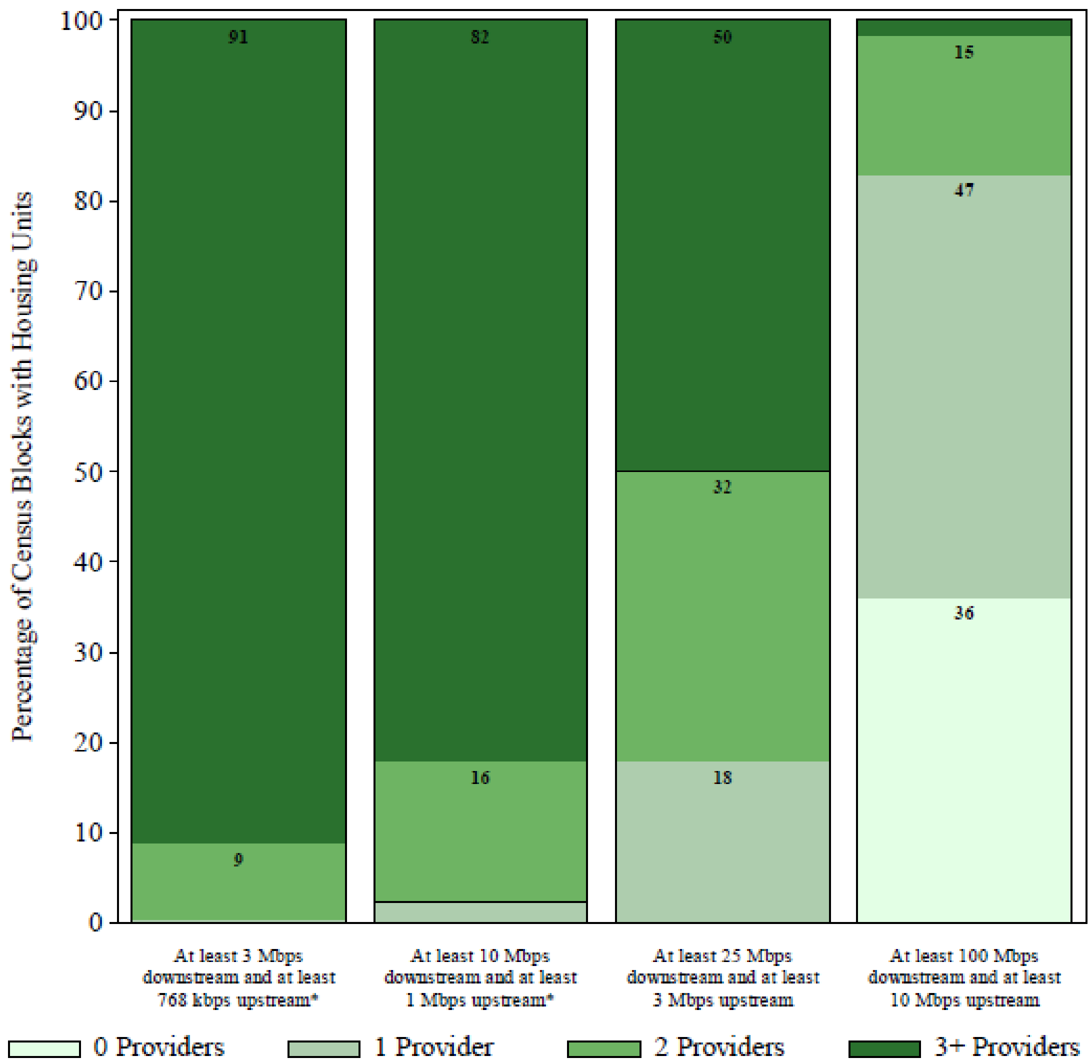
[2] FCC *Internet Access Services: Status as of June 30, 2017* report, published November 2018



Source: FCC

Figure 3. U.S. residential fixed connections by downstream speed

Moreover, with limited choice of service providers offering high-speed broadband connectivity services in many markets, Verizon's 5G fixed wireless offering appears to be targeting market segments where it can find the most success. As highlighted below, according to the latest FCC status report on Internet access in America, over 80% of "developed" census blocks (containing housing units) have only one or zero service provider offering 100 Mbps or greater fixed broadband service. With that much opportunity to be had, it is no surprise that Verizon is setting its sights on the fixed wireless opportunity in the near term as it awaits further maturity in the millimeter wave ecosystem for mobility.



Source: FCC

Figure 4. U.S. service provider choice for 100 Mbps+ residential fixed broadband is limited

5G Millimeter-Wave Fixed Wireless Network Cost

The fundamental question of fixed wireless access comes down this: how many potential households can be served by a single radio? In the 5G millimeter wave case, this is especially challenging as a millimeter wave does not travel far. Based on near line-of-sight (LOS) cases, we estimate that a 5G millimeter-wave, fixed wireless system can achieve hundreds or even Gbps throughput at a distance in hundreds of meters, assuming enough spectrum bandwidth is applied. Using Verizon's 5G fixed wireless commercial offering as a baseline reference and with certain estimates for equipment cost, we can calculate the "cost to pass" and "cost to connect" 5G fixed wireless homes depending on housing density which help determine where it makes sense to target the fixed wireless service.

The following key factors are assumed in our economic modeling of 5G millimeter-wave fixed wireless access:

Parameter	Value	Notes
5G fixed wireless service ($ per month)	$70	Verizon's 5G Home "standalone" pricing without bundled discount for mobile service plan ($50 for subscribers adding wireless data plan)
5G cell radius	0.2 km	We estimate that Verizon has chosen to offer competitive offering (300Mbps at cell edge) which requires about 200meter cell radius.[3]
"Cost to pass" (base station, spectrum, and other infrastructure costs)	$60K for 5G radio; $52K for spectrum; $270 site lease; $400 backhaul	$70K for 5G millimeter wave radio plus massive MIMO antenna. 800MHz of spectrum cost based on recent Straightpath and XO transactions. A blended cost of muni pole and traditional rooftop/tower site lease. Dark fiber for backhaul.
"Cost to connect" (CPE plus installation)	$150 per CPE; $200 per truck roll	Assume $150 per fixed wireless CPE. Assumed truck roll for CPE/antenna installation for optimal link budget
Churn rate (monthly)	2.5%	We estimate between 2-3% for monthly churn for broadband services. This figure drives customer lifetime value of 40 months (= 1/churn). The total monthly network cost (cost to pass + cost to connect) is amortized over the customer lifetime value.
Market penetration rate (% of households)	~30%	With a competitive offering, we estimate a full market penetration of 30% is possible especially in many markets where competition is limited

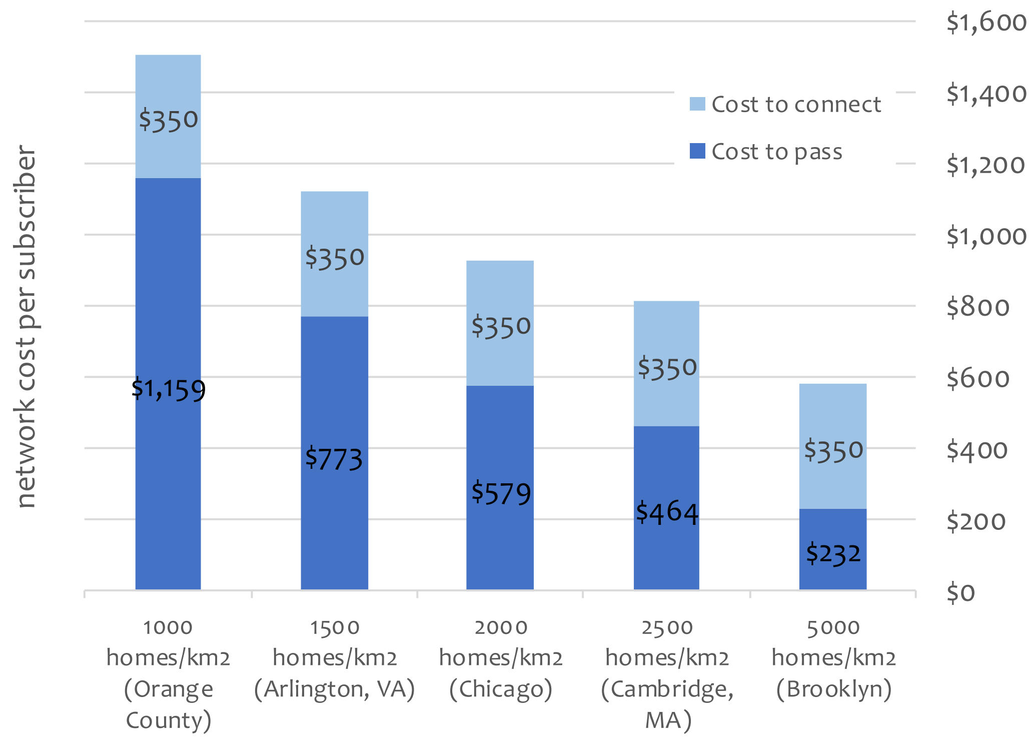
Source: Mobile Experts

Figure 5. 5G millimeter-wave Fixed Wireless Cost Modeling Assumptions

While fixed wireless systems can offer lower "passing" cost relative to wireline technologies like cable and fiber, it is important to note that cable footprint is pretty vast in the USA, which took several decades to build. Thus, most of the "passing" costs for cable have already been amortized and can be viewed as zero in real terms. However,

[3] In Qualcomm's 5GNR millimeter wave network coverage simulation, it cites 0.4Mbps/Hz spectral efficiency at cell edge. Moreover, some vendors and service providers are reporting a much longer range in LOS cases.

fixed wireless does offer time-to-market advantages compared to typical wireline technologies.



Note: cell radius = 200 meters

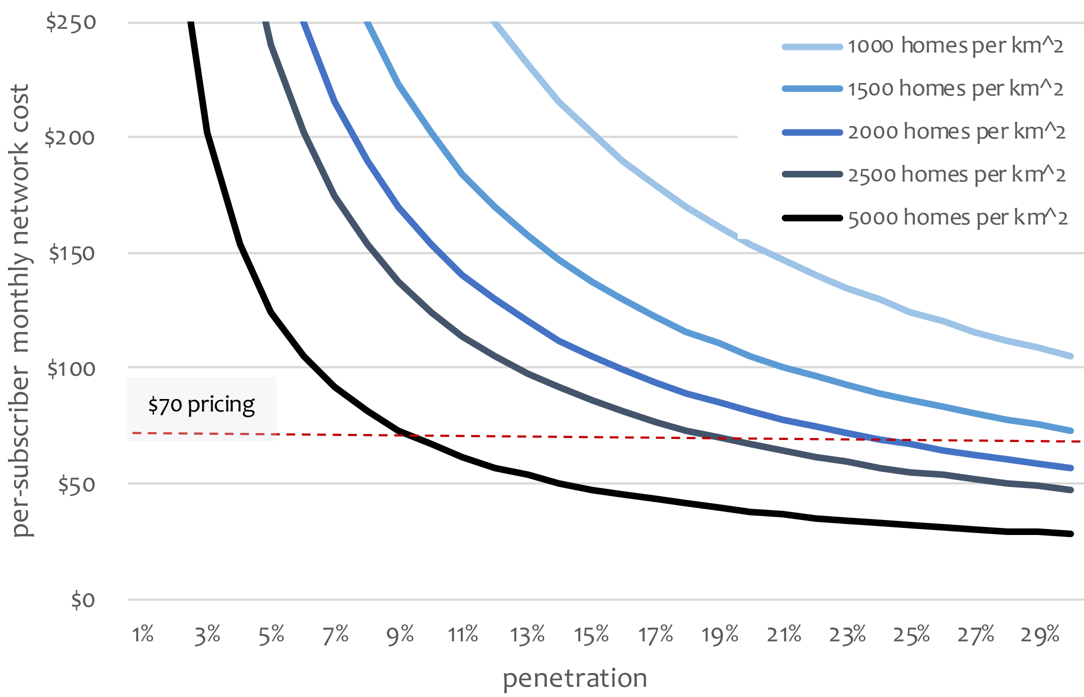
Source: Mobile Experts

Chart 1. 5G mm-wave FWA network costs at 200-meter cell range

As shown above, the "cost to pass" a home with 5G millimeter fixed wireless base station with a 200-meter cell radius (which we believe is the average cell radius of a Verizon's 5G millimeter-wave fixed wireless base station) ranges from ~$230 (at 5000 homes per km2) in a major urban areas like Brooklyn, NY to over $1150 in suburban environment like Orange County, CA. Comparing these costs to $600-$1200 for a fixed broadband buildout[4], the lower cost benefit of 5G fixed wireless technology is clear in highly dense urban areas but not so much in suburban markets. For the "cost to connect" a subscriber home, we have assumed $150 for CPE equipment and $200 for a "truck roll" for installation by a trained technician. While there is an opportunity for a self-install in certain cases where a subscriber is nearby a base station with line-of-sight links, we believe Verizon is rolling out a "white glove" installation and service provisioning to minimize follow-on customer calls which can increase on-going network operational expense.

[4] While Google Fiber cost in less-dense markets like Kansas City can be as low as ~$600 as reported (http://www.businessinsider.com/the-cost-of-building-google-fiber-2013-4), a typical "cost to pass" for fixed fiber or cable networks can range from $750-1200, according to MasTec.

Factoring in the costs to pass and connect a subscriber home, we can determine the unit network cost of delivering fixed wireless service to a subscriber home which is simply the sum of the two. Attaining a sufficient market penetration is key to lowering the "passing" cost. The goal here is to spread the total infrastructure cost by as many subscribers as possible (i.e., a higher market penetration). For example, at only 1% market penetration in a dense market like Brooklyn (5000 homes per km2), the "cost to pass" (per subscriber) comes to $23,200 (= $232 / 1%). At 10% market penetration, the "cost to pass" comes down to $2,320. Amortizing the total network cost over the customer lifetime value (40 months at 2.5% churn rate, or 1 / 2.5% = 40 months), the total monthly network cost comes to $67 per subscriber at 10% penetration.



Note: cell radius = 200 meters

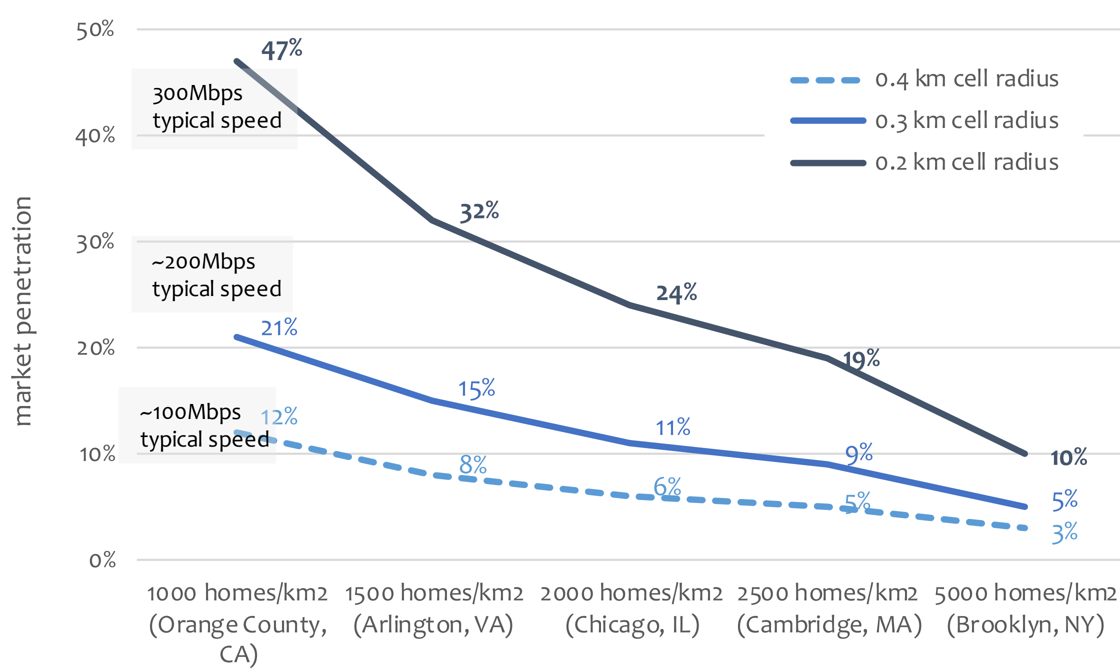
Source: Mobile Experts

Chart 2. 5G mm-wave Fixed Wireless network cost vs. % market penetration

At a $70 service target price (Verizon 5G *Home* pricing as noted in red dotted line in the figure above), we can see that the 5G millimeter-wave fixed wireless service, with 200-meter cell radius base stations, can achieve break-even points at various market penetrations depending on types of markets that it is targeted. For high-density markets like Brooklyn (5000 homes per km2), the break-even point is around 10% market penetration. For lower density markets like Arlington, VA (1500 homes per km2), the break-even point is above 30% market penetration. It is clear that 5G fixed wireless using millimeter wave spectrum should be targeted in high-density areas to achieve faster break-even at lower market penetration points. Mobile Experts believes that up to 30% market penetration is feasible in a rationally competitive market.

5G Millimeter-Wave Fixed Wireless Break-Even Analysis

Verizon's current 5G fixed wireless service is purposefully targeted at high-speed tiers (i.e., 300 Mbps typical speed) to compete against cable's fixed broadband offerings in the marketplace. This design goal requires shorter cell radius (200 meters by our estimate) to ensure that cell edge performance can match the advertised rates on "typical" speed. In other words, we estimate that Verizon's 5G fixed wireless service is represented by the top line in the figure below. As illustrated below, we believe Verizon's 5G fixed wireless service (300 Mbps "typical" speed at $70 pricing) should be targeted at dense markets, 1500 homes per km2 or greater, with reasonable expectations for market penetration to achieve profitable outcome. At the same time, it is possible to increase the probability of faster break-even if the fixed wireless service can be tailored for lower-speed tiers. For example, if an operator can compete effectively with a 200-Mbps offering that only requires 300-meter cell radius sites for 5G fixed wireless base stations for example, then the break-even points come down materially. For instance, the break-even point in an urban market like Chicago (2000 homes per km2) goes from 24% (the 300Mbps offer at $70) down to 11% if a 200Mbps service can be offered at $70.

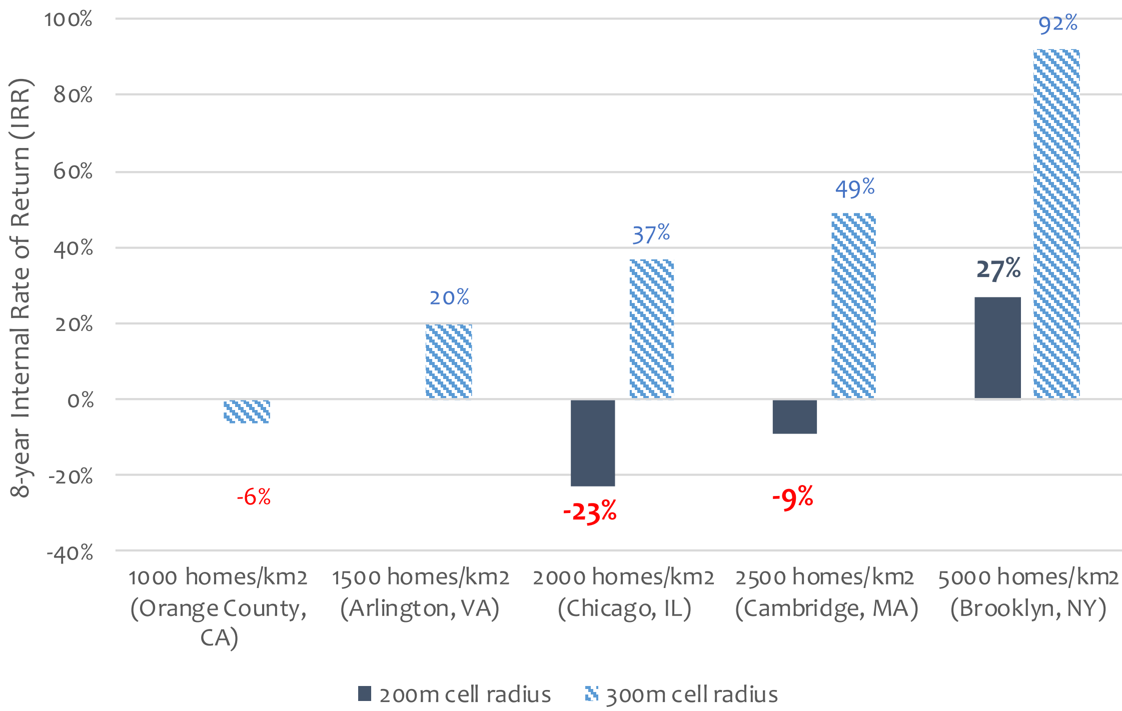


Source: Mobile Experts

Chart 3. 5G millimeter wave Fixed Wireless break-even analysis

5G MILLIMETER-WAVE FIXED WIRELESS PROFITABILITY ANALYSIS

Based on the network cost modeling and optimistic expectations around market penetration, reaching 28-32% in year 8, we estimate that 5G millimeter-wave fixed wireless can achieve positive returns in dense urban environments at relatively short cell range (200 meters) of 5G fixed wireless base stations. At a slightly longer range at a 300-meter cell radius, positive business case can be had even down to relatively sparse urban/suburban environments like Arlington, VA (1500 homes per km2). Not surprisingly, the 5G fixed wireless provides a relatively good economics for denser city-like or multi-dwelling unit environments where 5G investments can be targeted across a larger base of potential subscribers.



Notes: 1) $70 ARPU at year 1, growing at 4% CAGR; 2) market penetration ramp, reaching 28-33% at year 8

Source: Mobile Experts

Chart 4. 5G millimeter wave FWA profitability vs. housing density

5G MILLIMETER-WAVE FIXED WIRELESS SUMMARY

Verizon has taken the lead in commercialization of 5G fixed wireless using the millimeter wave spectrum. Verizon's recently launched *5G Home* service offers a glimpse into the capabilities and economics of the 5G millimeter-wave fixed wireless. While we believe the 5G millimeter-wave fixed wireless service can operate at different price/performance ranges, Verizon has chosen to tailor its system to operate at relatively high end to compete with cable offerings in the marketplace. Based on its "300Mbps at $70" offer, Verizon's 5G millimeter-wave fixed wireless service can achieve break-even points at reasonable market penetration rates (under 30%) in markets with housing density greater than 2000 homes per km2. Our ROI analysis, based on 8-year NPV and IRR, shows that Verizon's 5G fixed millimeter wave service can earn positive return in high-density markets like Brooklyn (with 5000 homes per km2). For less competitive markets, if the 5G millimeter-wave fixed wireless system can be adjusted (i.e., longer cell range) to operate at lower speed tier, the profitability increases and the ROI turns positive even in lower density markets.

3. Business Case 2: 5G Fixed Wireless with C-band in Rural

As noted in the first business case in this report, the 5G fixed wireless system leveraging large bandwidths in the millimeter wave spectrum can yield profitable outcome with competitive high-speed home broadband offerings, especially in dense urban markets. Despite physical challenges of having to employ greater number of smaller "coverage" footprints with 5G millimeter wave base stations to increase "homes passed," the 5G millimeter-wave fixed wireless system can deliver profitable service at reasonable expectations on market penetration in dense urban markets.

So, what about 5G fixed wireless system using C-band spectrum for rural markets? Presumably, the 3-4 GHz C-band spectrum can propagate much farther than the millimeter wave spectrum. Can a 5G fixed wireless system using the C-band can deliver adequate network capacity to meet the high-volume demand of fixed broadband service. Is the 5G fixed wireless investment justifiable for serving only the fixed wireless opportunity in the Rural market? If enough network capacity can be generated to serve both the mobile and fixed broadband demands, what is the ROI for the 5G investment? This second business case explores these questions.

Network Supply vs. Demand in Rural

Based on the following assumptions about network demand and cost estimates in Rural markets, the aggregate view of the network supply vs. demand is shown in Chart 5. Fixed and Mobile Data Demand vs. Network Capacity in Rural.

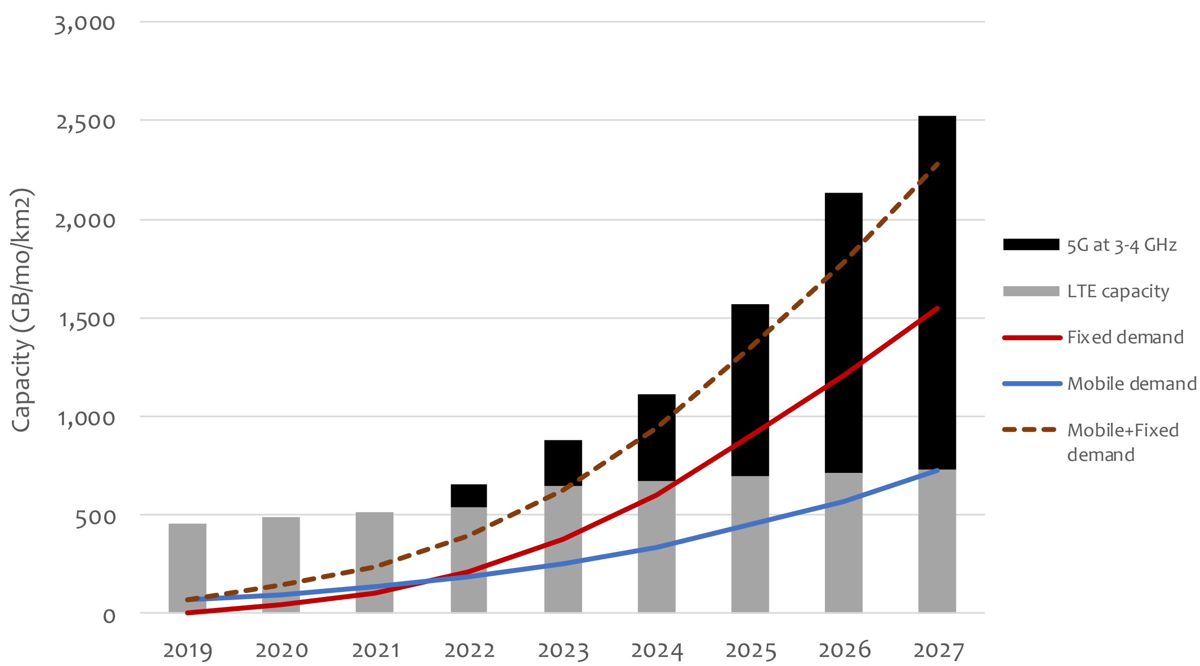
Parameter	Value	Notes
Fixed broadband usage (GB per month per home)	170 GB growing at 20% CAGR	Estimate based on broadband usage in WISP footprint
No. of fixed subscribers	0% (2019) growing to 30% (2027) of 4M targeted homes	Assume 20% of Rural homes are targeted for the fixed wireless service
Rural housing density	200 homes per km2	Based on US Census and estimate of a "Rural" market
"Cost to pass" (base station, spectrum, and other infrastructure costs)	\$60K for 5G radio; \$52K for spectrum; \$270 site lease; \$400 backhaul	\$70K for 5G millimeter wave radio plus massive MIMO antenna. 800MHz of spectrum cost based on recent Straightpath and XO transactions. A blended cost of muni pole and traditional rooftop/tower site lease. Dark fiber for backhaul.

Fixed "Cost to serve" (CPE plus installation)	$150 per CPE; $100 per truck roll or service cost	Assume $150 per fixed wireless CPE. Assumed truck roll for CPE/antenna installation for optimal link budget
Churn rate (monthly)	2.5%	We estimate between 2-3% for monthly churn for broadband services. This figure drives customer lifetime value of 40 months (= 1/churn). The total monthly network cost (cost to pass + cost to connect) is amortized over the customer lifetime value.
Fixed market penetration rate (% of households)	0% (2019) growing to 35% (2027)	With a competitive offering, we estimate full market penetration of 35% is possible especially in rural markets where competition is limited
Mobile traffic demand per user	10 GB per month (in 2019) growing at 25-35% CAGR	The year 0 (2019) estimate based on Ericsson Mobility Report showing average smartphone data usage of 12 GB/month in 2019. We assume lower-than-average usage in Rural.
No. of mobile subscribers	38% market share	Based on Verizon market share of mobile subscribers. We assume higher market share for the lead US operator who has higher Rural pop coverage.
Mobile "cost to serve"	25% of service revenue	Costs related to customer service including SG&A is assumed to be ~25% of service revenue (based on historical financial performance of top 2 US MNOs)
Mobile ARPU trend	2% annual increase (assuming continual network investment)	Assume that the mobile market will maintain "bounded" competition with rational pricing to maintain a gradual increase in service revenue.
Macro sites	~20,000 (in year 0)	Assume that a major mobile operator would leverage its mobile macro sites for fixed wireless with C-band rollout. Assume three-sector macro with 10% monthly utilization factor (a base station is fully utilized 10% in a month)

Source: Mobile Experts

Figure 6. 5G C-band Fixed Wireless for Rural Cost Modeling Assumptions

Our network supply vs. demand forecast of U.S. Rural markets suggests that while the LTE network can generate enough capacity to meet the projected growth in the mobile traffic demand. However, it suggests that the network capacity needs to be expanded in 2024-2025 timeframe to serve the growing high-volume fixed broadband connections in the Rural market. We believe that 5G massive MIMO base station leveraging high channel bandwidth available in the C-band is a great way to expand network capacity broadly. With appropriate 5G network investments, the network can supply enough capacity to satisfy both the fixed and mobile broadband traffic demands as delineated below.



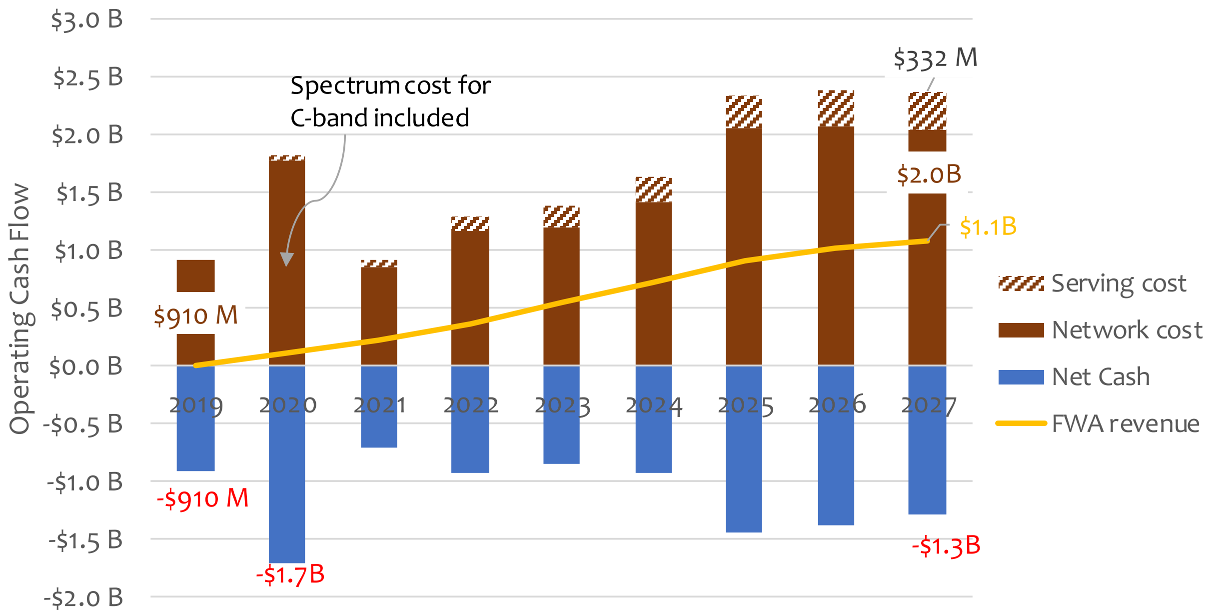
Note: Total network traffic demand in the US dense/urban area for a major MNO and network capacity generated from strategic investments of 5G radios in the 3.5GHz and millimeter wave bands

Source: Mobile Experts

Chart 5. Fixed and Mobile Data Demand vs. Network Capacity in Rural

VALUE OF 5G FIXED WIRELESS AT C-BAND FOR RURAL (FINANCIAL VIEW)

Targeting only the fixed wireless opportunity for 5G investments in Rural markets is not a sound business decision for a major mobile operator. If you can derive higher revenue from each GB delivered in mobile context, why would an operator dedicate that network capacity for the fixed wireless service. While this is obvious, the below figure delineates this point visibly. The "revenue vs. cost" cash flows clearly show that maintaining high network costs simply to target the fixed wireless revenue opportunity in Rural markets is not a smart idea. This business case yields negative cash flows during the 8-year forecast period in our analysis.



Note: Network costs reflect investment necessary to handle both mobile and fixed broadband demands. Net cash flow based on fixed wireless revenue only (excludes mobile service revenue).

Source: Mobile Experts

Chart 6. Operating Cash Flow of 5G Fixed Wireless in Rural

So, what about the case where LTE network capacity is dedicated for the fixed wireless revenue opportunity without 5G investments? In this particular scenario, the net cash flows are negative. Moreover, the LTE network runs out of capacity in the year 6, and revenue declines, as the rising fixed wireless traffic demand exceeds the LTE capacity.

1) LTE network dedicated to serve only the Fixed Wireless opportunity without 5G investment									
CASH FLOW	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**
Revenue	$0 M	$108 M	$217 M	$361 M	$542 M	$723 M	$704 M	$601 M	$512 M
Network Costs	$816 M	$840 M	$847 M	$863 M	$879 M	$895 M	$911 M	$944 M	$968 M
CPE/Subscriber Costs	$0 M	$42 M	$75 M	$121 M	$179 M	$233 M	$287 M	$313 M	$332 M
Cash Flow	**-$816 M**	**-$774 M**	**-$705 M**	**-$623 M**	**-$516 M**	**-$405 M**	**-$494 M**	**-$656 M**	**-$787 M**
NPV	**-$3,780 M**								

For the case where the operator makes 5G network investment to handle both mobile and fixed broadband traffic demands but only targets the fixed wireless revenue opportunity, the net cash flows become even worse (no surprise here). In essence, this scenario is depicted in Chart 6. Operating Cash Flow of 5G Fixed Wireless in Rural above.

2) LTE+5G network investments to meet projected Mobile and Fixed data demand but serve only the Fixed Wireless opportunity

CASH FLOW	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Revenue	$0 M	$108 M	$217 M	$361 M	$542 M	$723 M	$904 M	$1,012 M	$1,084 M
Network Costs	$910 M	$1,776 M	$847 M	$1,169 M	$1,206 M	$1,411 M	$2,059 M	$2,075 M	$2,042 M
CPE/Subscriber Costs	$0 M	$42 M	$75 M	$121 M	$179 M	$233 M	$287 M	$313 M	$332 M
Cash Flow	**-$910 M**	**-$1,710 M**	**-$705 M**	**-$929 M**	**-$843 M**	**-$921 M**	**-$1,443 M**	**-$1,376 M**	**-$1,290 M**
NPV	**-$6,377 M**								

Finally, a rational scenario for 5G fixed wireless investment in Rural market should target both the mobile and fixed wireless opportunities. For a major mobile operator already serving the mobile broadband users in the Rural, 5G network investment should consider adding enough network capacity to handle mobile and fixed wireless demands. With a huge mobile subscriber base already, the return on investment of 5G network investment becomes evidently clear.

3) LTE+5G network investments to serve both the Fixed Wireless and Mobile opportunity

CASH FLOW	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Revenue	$10,504 M	$11,036 M	$11,582 M	$12,177 M	$12,821 M	$13,479 M	$14,152 M	$14,766 M	$15,360 M
Network Costs	$910 M	$1,776 M	$847 M	$1,169 M	$1,206 M	$1,411 M	$2,059 M	$2,075 M	$2,042 M
CPE/Subscriber Costs	$2,626 M	$2,774 M	$2,916 M	$3,075 M	$3,249 M	$3,422 M	$3,599 M	$3,752 M	$3,900 M
Cash Flow	**$6,968 M**	**$6,486 M**	**$7,819 M**	**$7,933 M**	**$8,366 M**	**$8,646 M**	**$8,493 M**	**$8,940 M**	**$9,417 M**
NPV	**$45,585 M**								

The net cash flow chart below summarizes the three scenarios for 5G fixed wireless investment in Rural, and clearly shows that 5G network investment should be prioritized for mobile first before considering fixed wireless opportunities. More specifically, if a major mobile operator wants to target fixed wireless opportunity in rural markets, it needs to be targeted specifically to localized region where 5G investment at a site needs to factor in mobile traffic demand first and foremost before expanding network capacity for fixed wireless revenue opportunities near that site.

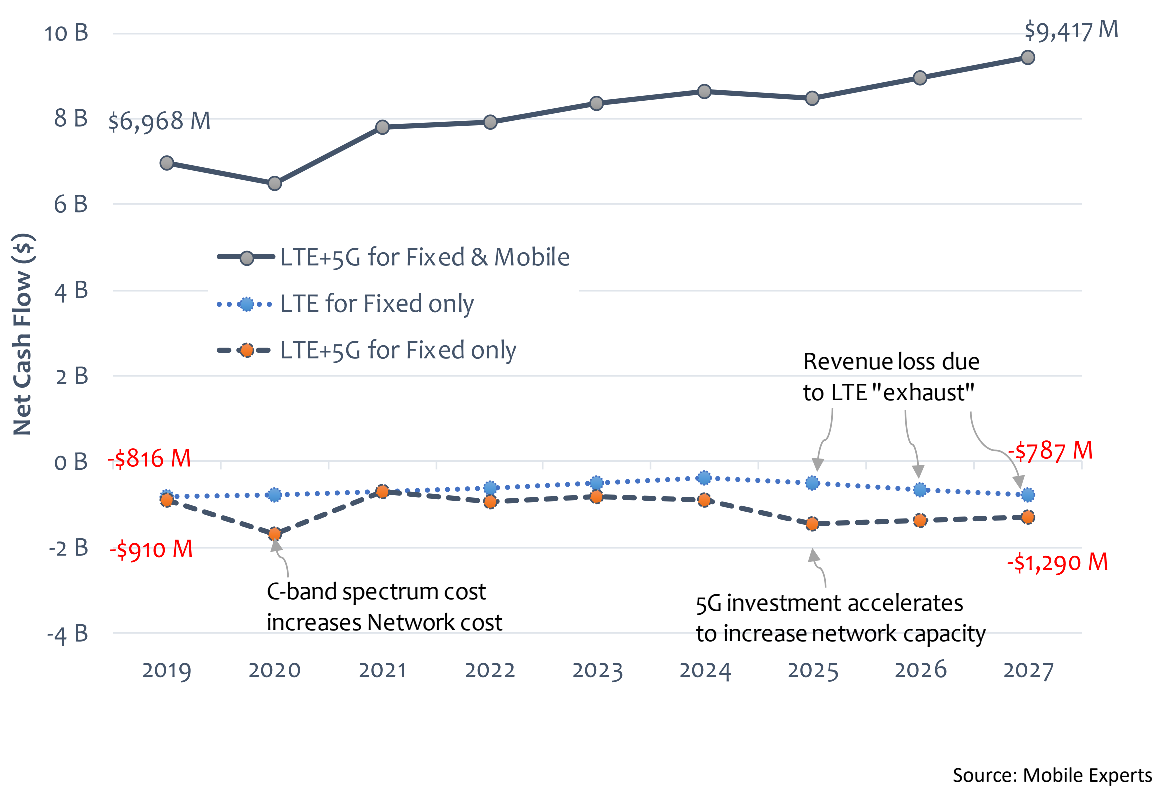


Chart 7. Net cash flow analysis of LTE+5G Fixed Wireless at Sub-6GHz

5G Fixed Wireless in Rural Summary

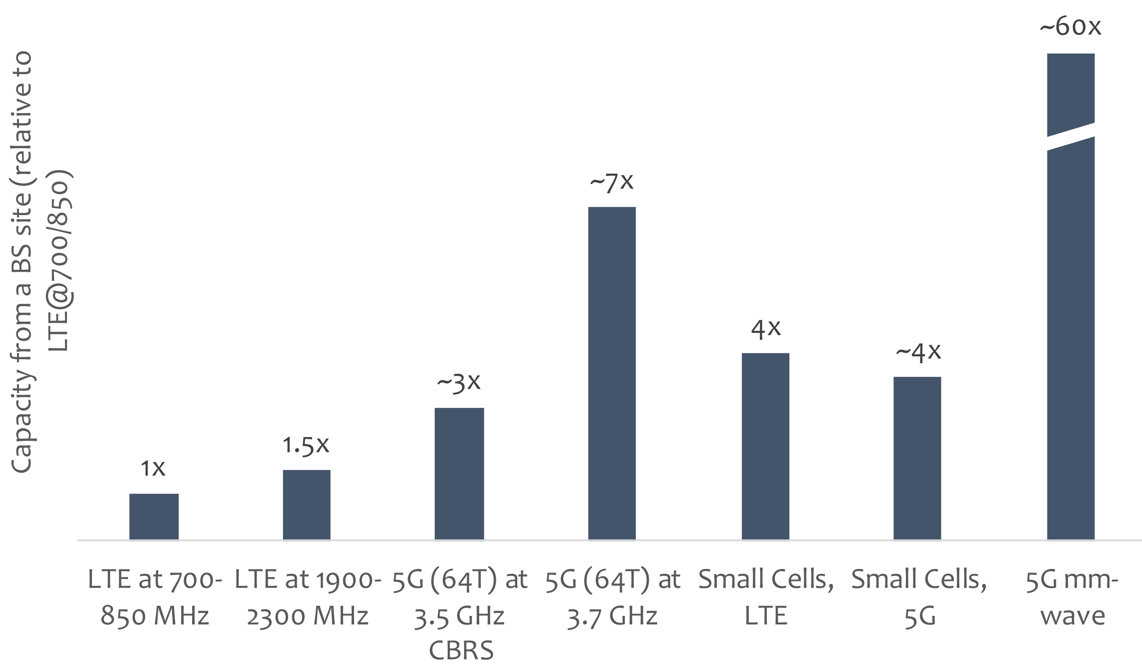
A clear conclusion from our study of the 5G fixed wireless investment for rural market is that the limited revenue opportunity from fixed wireless in Rural market does not warrant heavy 5G investment. Dedicating the entire LTE and 5G network capacity of a major mobile operator for fixed wireless home broadband opportunity in sparsely populated rural market yields negative ROI – negative cash flow and NPV! It is better for the operator to target the mobile broadband opportunity, where subscribers are willing to pay more for each GB of data delivered in mobile context than in fixed broadband scenario (i.e., mobility premium). 5G investments in Rural markets should include the mobile broadband opportunity in concert with fixed wireless revenue opportunity. With additional investment to generate enough network capacity for both mobile and fixed broadband traffic demands, the operator can generate a significantly higher ROI – thanks to much higher mobile service revenue opportunity to offset the additional network investments.

4. Business Case 3: 5G for Mobile Broadband (U.S. Tier-One Operator)

The third 5G use case explored in this report is the simple application of leveraging 5G to serve existing mobile broadband subscribers. A key premise of this use case is that a leading US mobile operator is motivated to leverage more efficient 5G technologies including massive MIMO and the additional spectrum in the 3.7-4.2 GHz C-band, the 3.5 GHz CBRS band, and millimeter wave spectrum to increase network capacity to keep ahead of the rising mobile demand. Based on the lower "cost per GB" unit economics of 5G (as studied in last year's *5G Business Case 2017* report), the operator is motivated to deploy 5G infrastructure aggressively to drive down the unit cost of delivering gigabyte lower while expanding the network capacity.

Network Capacity Expansion with 5G (and LTE)

Based on assumptions about the number of macro sites (~65,000) and small cells (35,000 by 2019) deployed to date, an estimate of the leading operator's average monthly utilization of base stations, and total spectrum available for deployment, we surmise that the lead operator can generate different levels of network capacity as shown below. It should be noted that the amount of network capacity that a particular base station (BS) site can generate depends on technology choice (e.g., LTE or 5G, massive MIMO configuration, etc.) and amount of spectrum deployed at that site.

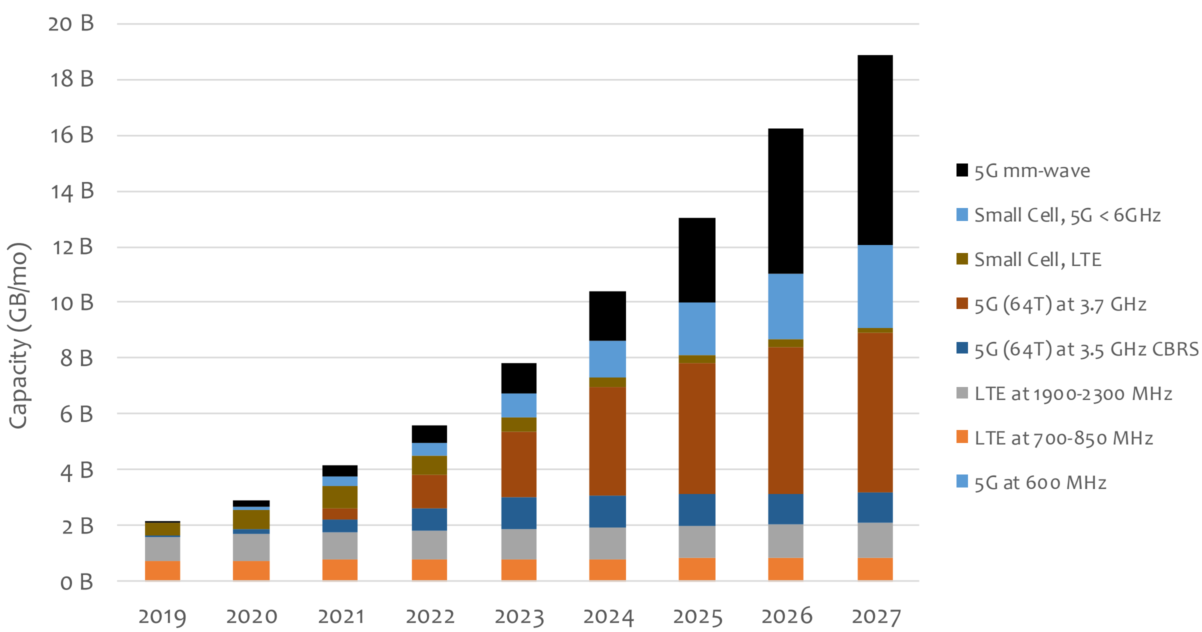


Source: Mobile Experts

Chart 8. Leading US operator's technology and spectrum choices to increase capacity

For example, 5G base station leveraging 64T64R massive MIMO on 100MHz of 3.7 GHz C-band can produce seven times more "GB/month" capacity than LTE (4x4) base station utilizing 40 MHz of total spectrum across 700-800 MHz. The corresponding capacity gain is a result of higher spectral efficiency from massive MIMO antenna gain as well as bigger channel bandwidth afforded with the C-band spectrum. While the dramatic capacity gain from a 5G millimeter wave BS seems tempting, we believe this will be applicable only in select "hotspot" areas as coverage limitation of such system will limit its widespread application.

Based on our modeling of the lead operator's network investment choices, including availability, maturity, and timing of certain technology and spectrum options, the following network capacity "map" is derived. In the near term, we expect the lead operator to deploy CBRS and LAA small cells to increase network capacity in demanding "hotspot" locations. In mid-term, 5G massive MIMO on the 3.7 GHz C-band will play a vital role in expanding capacity broadly. Lastly, 5G millimeter wave is expected to play a critical role in expanding capacity in very demanding hotspot locations in urban areas.

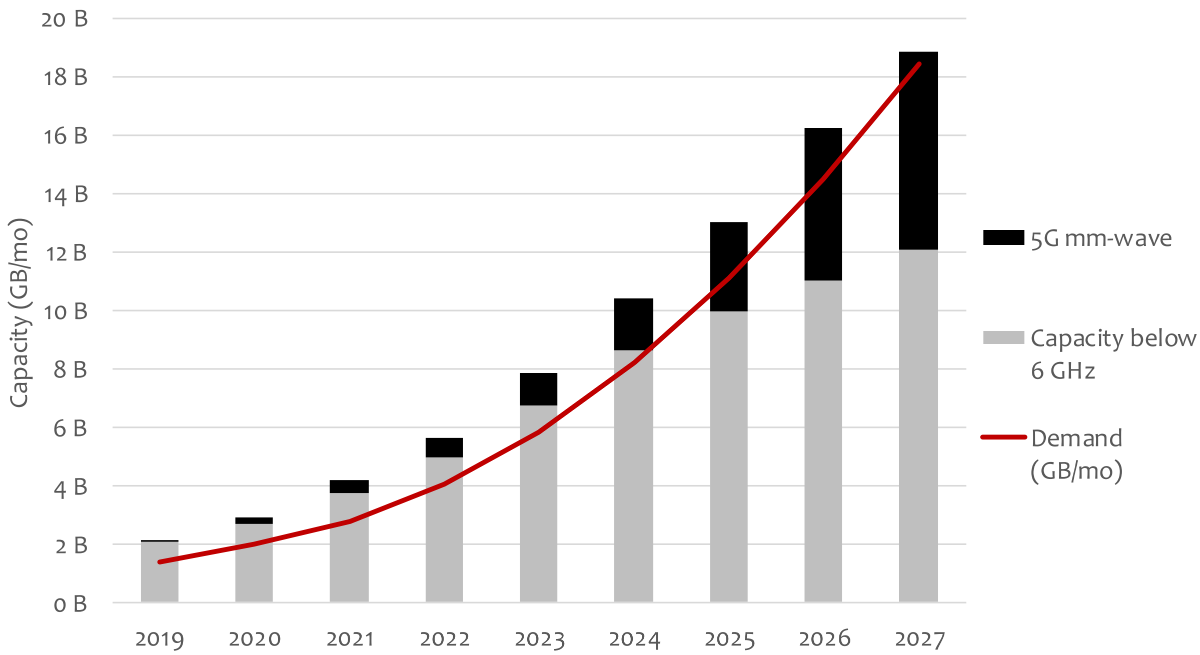


Source: Mobile Experts

Chart 9. Network Capacity by Technology and Spectrum of a Leading US Operator

U.S. Tier-One Mobile Network Supply vs. Demand – Aggregate View

Based on the demand trajectory of the operator's subscriber base, which we estimate to be somewhere between 35-40% yearly growth, our model suggests that the network capacity based on sub-6GHz spectrum, including the new C-band and CBRS, is not enough to keep up with the mobile broadband demand. The sub-6GHz capacity "exhaust" (in 2024-2025) will force the operator to deploy 5G millimeter infrastructure in targeted areas to satisfy the demand – possibly through in-building systems.



Source: Mobile Experts

Chart 10. Mobile Network Supply and Demand of a Leading US Operator

U.S. Tier-One Mobile Network Supply vs. Demand – Morphological View

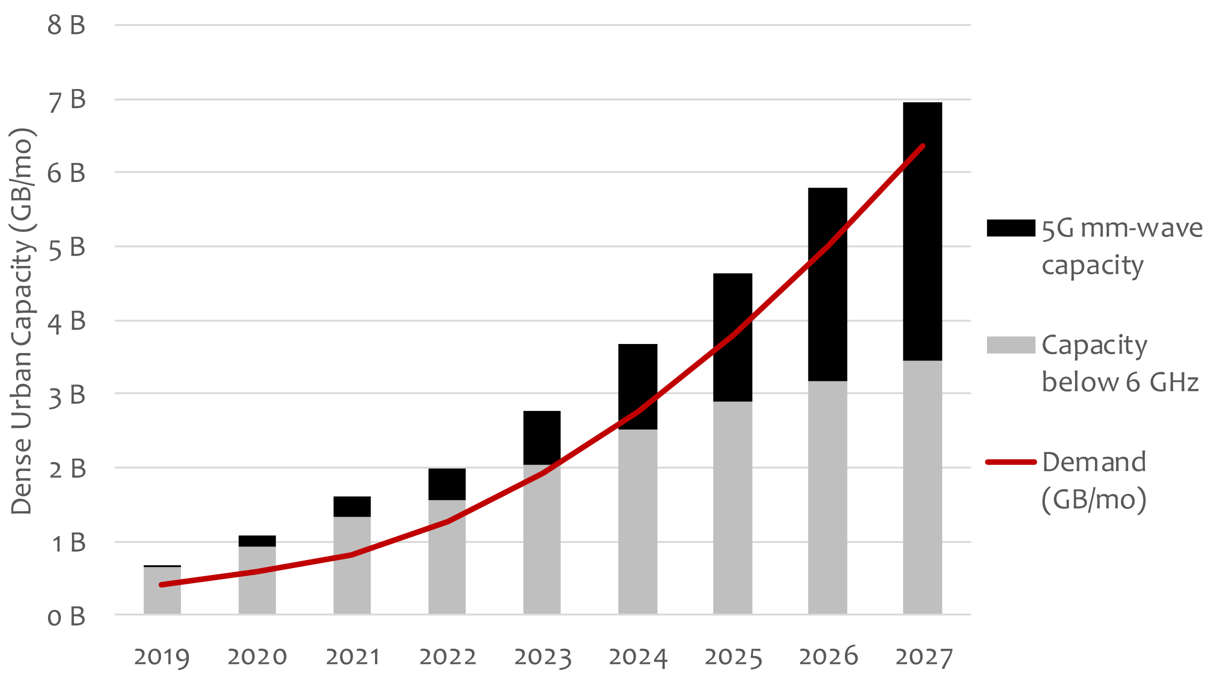
To understand where network investments will be made requires us to take a closer look at where the mobile data demand is the greatest. A logical premise is that an operator will spend capital expenditure where it is needed the most – i.e., increase network capacity to keep ahead of the demand, but not to over-expand. Increasing network capacity is a function of:

1. Number of base stations (macro and small cells) – more sites are needed to expand coverage and capacity through densification;
2. Number of spectrum carriers – more spectrum implies more channel bandwidth available to carry mobile data traffic;
3. Technology choices (LTE, 5G, massive MIMO, etc.) – employing better technology and number of antennas increases spectral efficiency (i.e., drive more bits per Hz).

Based on our view of the US morphology in terms of population coverage and macro site distribution (see Appendix at the end of the report), we have identified the following view of the network demand vs. (projected) capacity supply that will be invested by a leading US mobile operator – assuming that the operator maintains its market share during the forecast period over the next 9 years.

Dense Urban

In our "Dense Urban" model, we assume that the demand in dense urban area is disproportionately higher than residential population in the area due to suburban population moving into urban areas during "peak" work hours during the day. Moreover, we have attributed higher mobile data usage per user compared to less populated regions. Our view is that people in urban areas consume more data than folks in rural areas.



Source: Mobile Experts

Chart 11. Dense Urban Mobile Network Supply vs. Demand of a Leading US Operator

Based on higher-than-average mobile data usage growing at 40-50% CAGR in the near term and relatively limited licensed spectrum on hand, our model suggests that the leading US mobile operator will run out of network capacity solely relying on sub-6GHz spectrum in 2023 despite the projected use of unlicensed and shared spectrum via LAA and CBRS.[5] To keep up with the projected demand, our model includes adding 5G millimeter wave small cells to deploy large bandwidth available in the millimeter wave bands. Our model suggests that the leading mobile operator needs to tap 5G millimeter wave, starting 2023, which implies that it needs to start laying the foundation, in terms of fiber backhaul and site acquisitions, now! It should be noted that our model does not account for a possible scenario of the operator deploying additional sub-3GHz spectrum, e.g., AWS spectrum via acquisition or partnership with DISH, to increase network capacity.

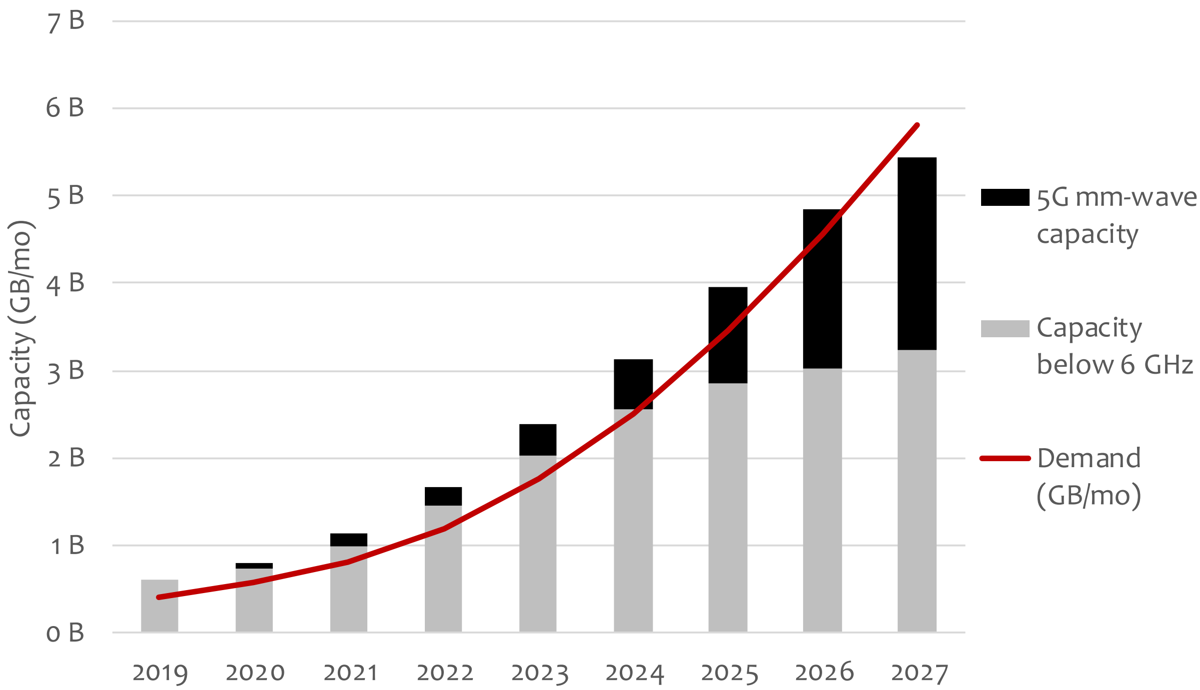
Based on our modeling of dense urban areas, the 5G millimeter wave network investment will be essential in its network plans to keep up with higher-than-average mobile traffic growth that is forecasted. In addition to the 5G millimeter wave network deployment, the lead operator will leverage 5G (64T) base stations to generate the majority of the "Capacity below 6GHz" shown in the figure above.

Urban

Our "Urban" model is based on slightly lower mobile data usage per user as compared to the "Dense Urban" case. Our model indicates that the leading US mobile operator will run out of network capacity solely based on sub-6GHz spectrum in 2024 (lasting slightly longer than the Dense Urban case where higher data usage results in a quicker "exhaust"). Again, this projection includes the use of unlicensed and shared spectrum via LAA and CBRS.[6]

[5] Our model assumes 60 MHz of unlicensed spectrum use via LAA small cells and 40 MHz of the 3.5 GHz CBRS band via 5G (64T) base stations across a portion (up to 40%) of macro sites

[6] For the Urban case, our model assumes 60 MHz of unlicensed spectrum use via LAA small cells and 40 MHz of the 3.5 GHz CBRS band via 5G (64T) base stations across a portion (up to 30%) of macro sites



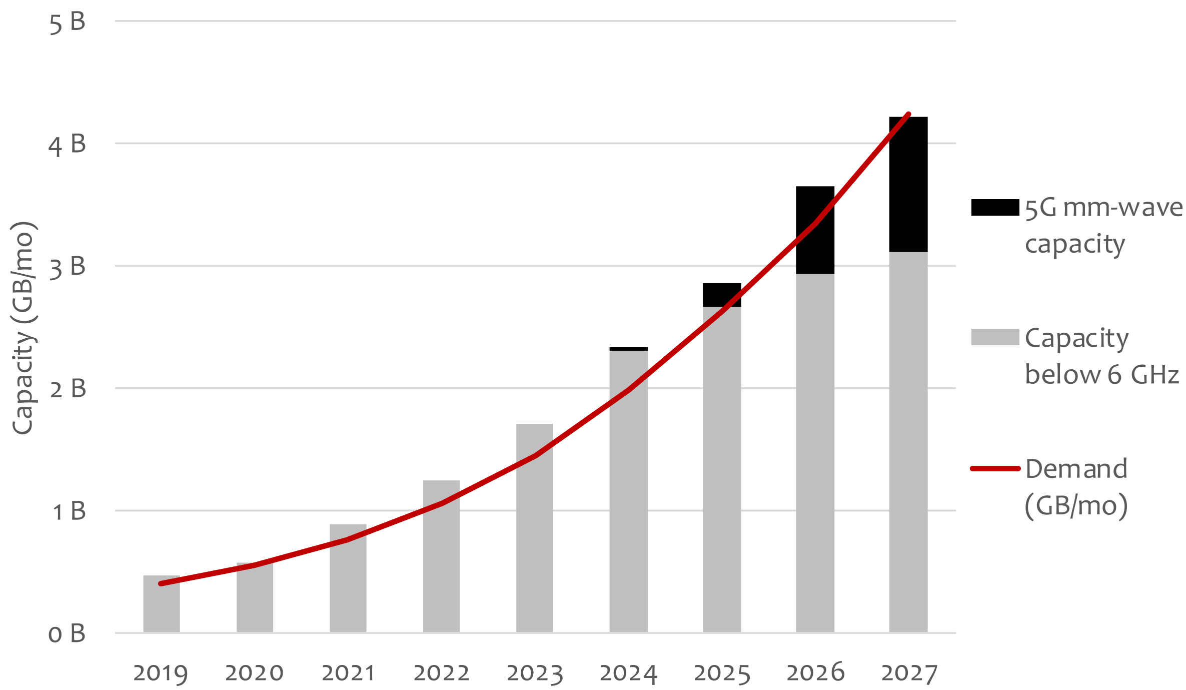
Source: Mobile Experts

Chart 12. Urban Mobile Network Supply vs. Demand of a Leading US Operator

For the Urban case, the 5G millimeter wave network capacity needs to be in place by 2024 to satisfy the growing mobile traffic. It should be noted that our modeling assumes that lead operator will quickly ramp up the C-band (3.7-4.2 GHz) deployment via 5G (64T) base stations starting 2021. While not explicitly shown above, the network capacity generated from 5G/C-band base deployments make up the majority of the "Capacity below 6GHz" in the figure above.

Suburban

Our "Suburban" model indicates that the leading US mobile operator will run out of network capacity solely based on sub-6GHz spectrum in 2025-2026. Again, this projection includes the use of unlicensed and shared spectrum via LAA and CBRS.



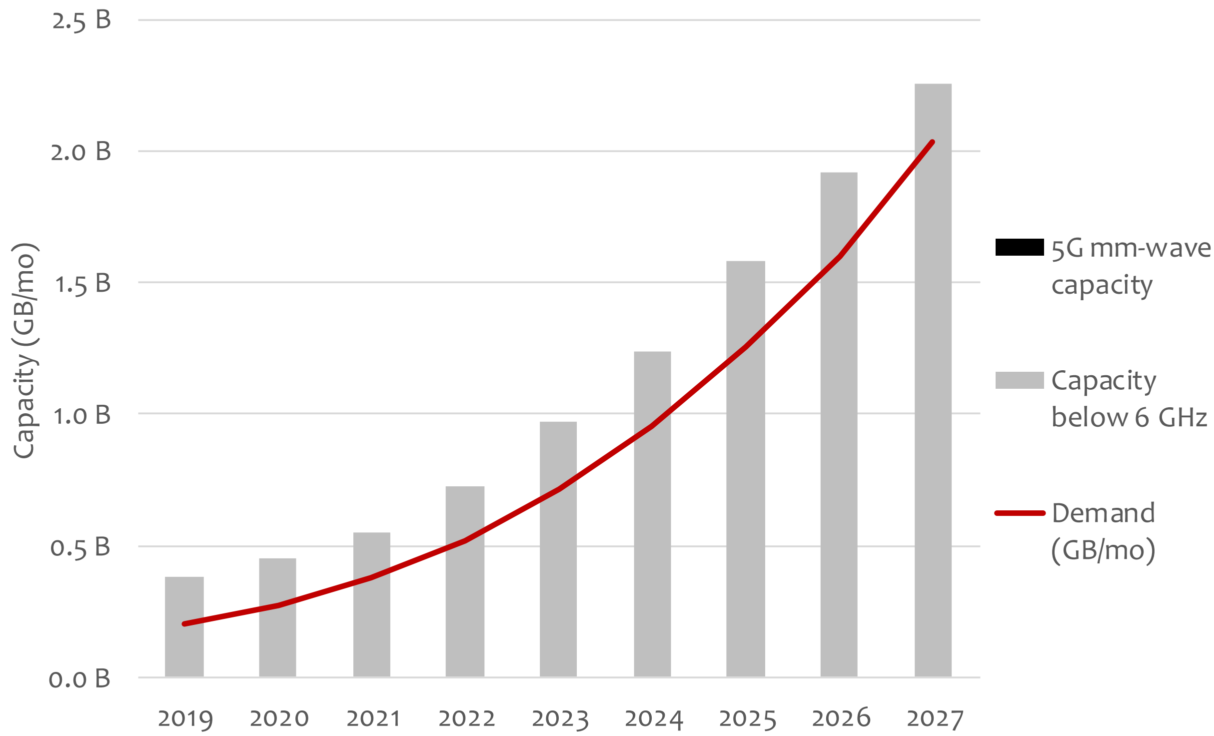
Source: Mobile Experts

Chart 13. Suburban Mobile Network Supply vs. Demand of a Leading US Operator

For the "Suburban" case, the 5G millimeter wave network capacity needs to be in place by 2025 to satisfy the growing mobile traffic. Again, our modeling assumes that lead operator will quickly ramp up the C-band (3.7-4.2 GHz) deployment via 5G (64T) base stations starting 2021 since it is expected to provide a broad and deep coverage and capacity solution with possibly 100 MHz of channel bandwidth available to deploy in concert with massive MIMO to provide very high spectral efficiency.

Rural

With lower-than-average mobile data usage, our "Rural" model indicates that the leading US mobile operator can meet the projected mobile data demand with available sub-6GHz spectrum including unlicensed spectrum use via LAA and shared spectrum via CBRS. It should be noted that our model includes deployment of the C-band (3.7-4.2 GHz) via 5G (64T) base stations starting 2022 with relatively more gradual ramp than the "Suburban" case since the aggregate demand is expected to be lower than other areas.



Source: Mobile Experts

Chart 14. Rural Mobile Network Supply vs. Demand of a Leading US Operator

VALUE OF 5G INVESTMENTS BY U.S. TIER-ONE OPERATOR (FINANCIAL VIEW)

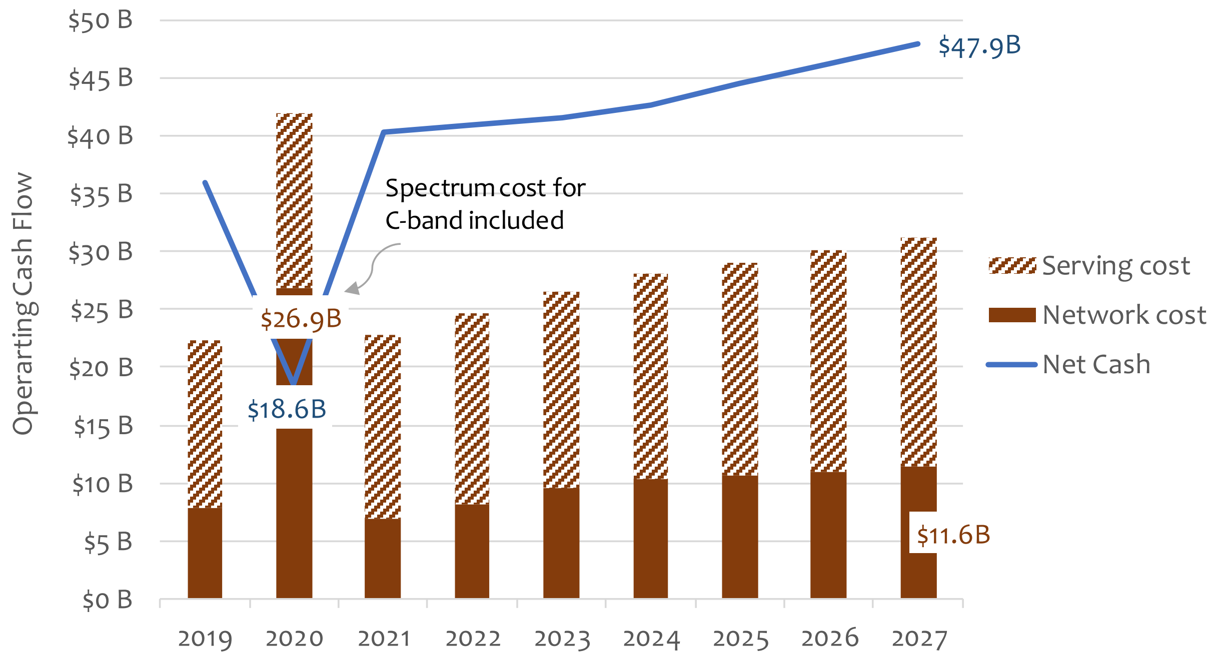
One of the foundational pillars of our LTE/5G investments for the leading US operator is that it will make "just enough" network investment to facilitate projected mobile network demand. (Of course, operators will make sure to have enough "buffer room" in their network capacity to account for unforeseen growth in the demand trajectory.) Based on the prospect for moderate growth in service revenue, we have modeled a high-level operating cash flow based on our view of the network CAPEX and OPEX that are needed to generate network capacity to meet the growing mobile network demand as delineated in the various "supply vs. demand" figures noted previously. (Please refer to the MEXP-5GBB-18-BC spreadsheet for detailed figures.)

The following assumptions about network demand and cost estimates are applied in our 5G mobile broadband model:

Parameter	Value	Notes
mobile traffic demand per user	10-15 GB per month (in 2019) growing at 35-40% CAGR	The year 0 (2019) estimate based on Ericsson Mobility Report showing average smartphone data usage of 12 GB/month in 2019. We assume higher-than-average usage in Dense Urban and lower-than-average usage in Rural.
No. of subscribers	35% market share	Based on Verizon market share of mobile subscribers. We assume higher market share for the lead US operator who has higher Rural pop coverage.
Cost to serve	25% of service revenue	Costs related to customer service including SG&A is assumed to be ~25% of service revenue (based on historical financial performance of top 2 US MNOs)
ARPU trend	2% annual increase (assuming continual network investment)	Assume that the mobile market will maintain "bounded" competition with rational pricing to maintain a gradual increase in service revenue.
Macro sites	65,000 (in year 0)	Assume that the operator will gradually increase macro sites to expand coverage and capacity with C-band rollout. Assume three-sector macro with 15% monthly utilization factor (a base station is fully utilized 15% in a month)
Small Cells	35,000 (in year 0)	Assume that the operator will densify network through small cells in certain cases (e.g., LAA, 5G mm-wave).

Source: Mobile Experts

Figure 7. 5G Mobile Broadband (US Lead Operator) Cost Modeling Assumptions

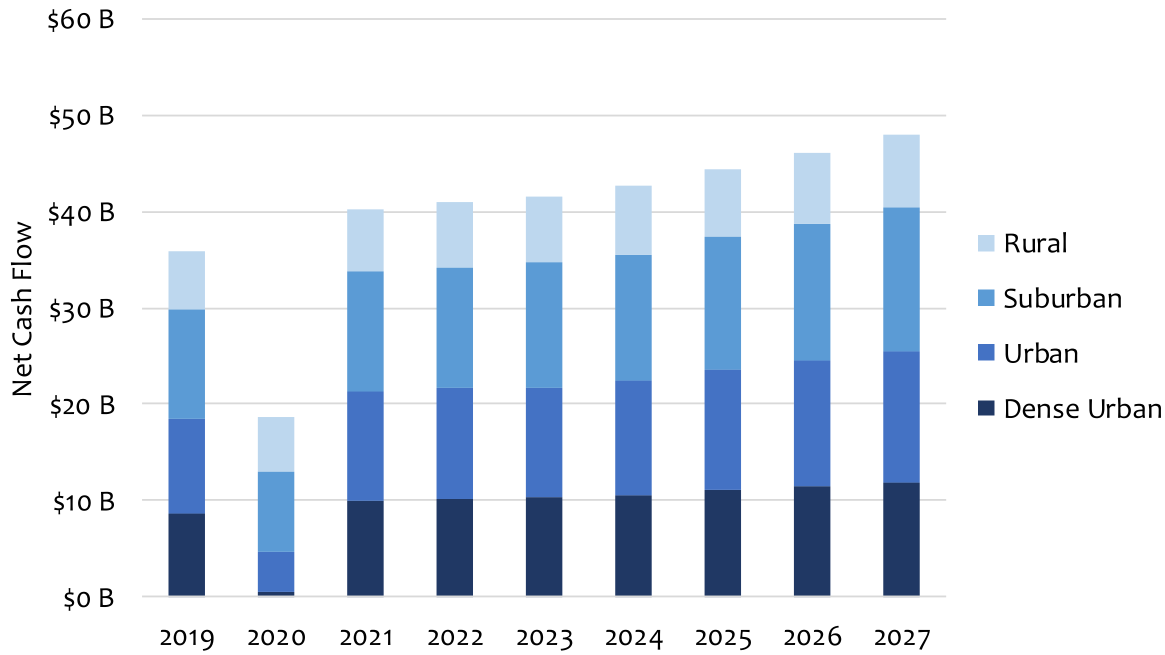


Source: Mobile Experts

Chart 15. Operating Cash Flow of a Leading US Mobile Operator

The model assumes the mobile broadband service revenue as the primary source of revenue and does not account for equipment revenue, from device installment plans for example, or service revenue associated with connected devices in calculating the operating cash flow. The significant network cost increase in the year 2020 reflects the spectrum cost of the C-band (3.7-4.2 GHz). While the spectrum costs associated with CBRS PAL license and the millimeter wave spectrum are factored in the year 2019 network costs, they are relatively small -- a total cumulative cost estimate of ~$2B for multiple licenses to patch together a nationwide footprint. In comparison, Mobile Experts estimates that roughly 10x that amount for the C-band licenses for a nationwide footprint.

It should be carefully noted that in our simplified cash flow analysis, the cost of equipment associated with user devices like smartphones is not factored in to provide a simple "network investment vs. service revenue" view. In reality, of course, smartphone device purchase and device installment plans are big aspects of selling a mobile service today.



Source: Mobile Experts

Chart 16. Net Cash Flow by Morphology of a Leading US Mobile Operator

The Net Cash Flow as shown in the previous figure can be segmented into the different morphological view. While the net cash flows across Dense Urban, Urban, Suburban, and Rural do not defer much except for the year 2020 due to a very high cost of the C-band spectrum licenses[7], the negative network cost impact is heavily skewed towards the Dense Urban case since spectrum cost tends to be significantly more expensive in dense urban than rural markets. Our model reflects this reality.

U.S. Tier-One Operator's 5G Business Case Summary

For the leading US mobile operator with relatively limited spectrum holdings and lots of subscribers, having a leading network capacity (and quality) is paramount to maintaining a leading market share. Despite the new technologies to harness unlicensed and shared spectrum through LAA and CBRS, the need for additional spectrum and capital investments on network infrastructure becomes obvious in later years if the current demand trajectory (i.e., ~40% yearly growth) holds. Based on our modeling of projected LTE and 5G investments, without the over-investment beyond what is needed to keep ahead of the demand, the 5G investment on both sub-6Hz (e.g., refarming existing spectrum towards 5G and new investments using the C-band) and the millimeter wave spectrum becomes necessary.

[7] While our modeling assumes the C-band spectrum auction to take place in 2020, it may get postponed depending on the series of CBRS PAL and millimeter wave auctions that are expected in the next few years.

While a high-level aggregate view of our model Chart 10. Mobile Network Supply and Demand of a Leading US Operator across the different urban morphology suggests that the need for 5G millimeter wave infrastructure deployment is not necessary until 2024-2025, the capacity "shortfall" becomes more acute – and the need for 5G millimeter wave infrastructure deployment becomes more urgent -- in denser areas. According to our model, the network capacity "exhaust" solely based on sub-6GHz spectrum occurs much earlier in the Dense Urban areas (2023-2024).

Moreover, our model suggests that the capacity "shortfall" becomes problematic in later years in the Urban and Suburban areas. The operator needs to add more small cells, more 5G millimeter wave sites, and in-building systems to offload traffic. While we have assumed about 30% penetration of 5G millimeter wave sites, we do not believe the operator will be able to rely heavily on network capacity generated from the millimeter wave infrastructure (in outdoor context) due to propagation limitations of such system.

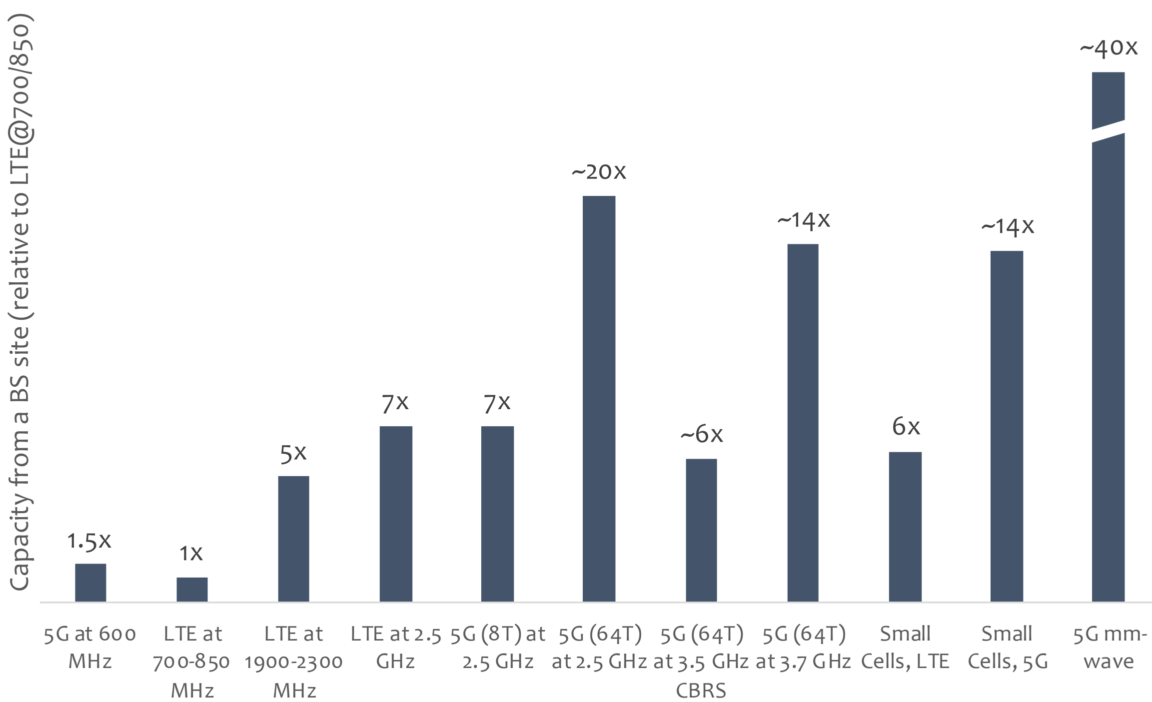
In summary, for the US tier-one operators, 5G business case is clear. Making 5G investment across all available spectrum, including the challenging millimeter wave case, becomes vital in order to maintain network capacity (and quality) leadership in order to satisfy the growing mobile broadband demand. Maintaining the network supremacy in terms of performance, quality, and cost-competitiveness is critical to maintaining market share and lower churn.

5. Business Case 4: 5G for Mobile Broadband (New T-Mobile)

The fourth 5G use case explored in this report is a case for a hypothetical "New T-Mobile" in leveraging 5G to serve combined base of T-Mobile and Sprint mobile subscribers. Similar to the previous case of the leading US operator, a key premise of this use case is that the New T-Mobile is motivated to leverage more efficient 5G technologies including massive MIMO and broad spectrum including the new 3.7-4.2 GHz C-band, the 3.5 GHz CBRS band, and millimeter wave spectrum to increase network capacity to increase network capacity to lower the unit cost of delivering gigabyte.

Network Capacity Expansion with 5G (and LTE)

Based on assumptions about the number of macro sites and small cells deployed to date, an estimate of the leading operator's average monthly utilization of base stations, and total spectrum available for deployment, we surmise that the lead operator can generate different levels of network capacity as shown below. It should be noted that the amount of network capacity that a particular base station (BS) site can generate depends on technology choice (e.g., LTE or 5G, massive MIMO configuration, etc.) and amount of spectrum deployed at that site. For example, a 5G base station leveraging 64T64R massive MIMO on 100MHz of 3.7 GHz C-band can produce 14x more "GB/month" capacity than LTE (4x4) base station utilizing 20 MHz of total spectrum across 700-800 MHz.

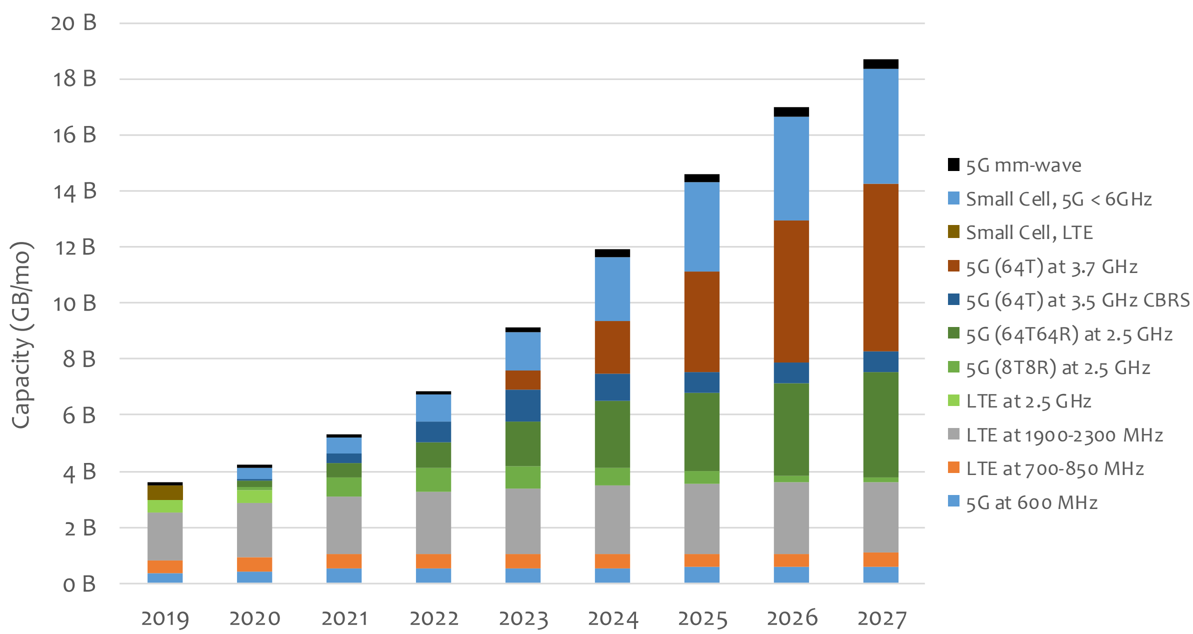


Source: Mobile Experts

Chart 17. "New T-Mobile" technology and spectrum choices to increase capacity

It should be noted that the New T-Mobile has a huge swath of 2.5 GHz spectrum (from Sprint) to generate significant network capacity. Again, while the dramatic capacity gain from a 5G millimeter wave BS seems tempting, we believe this will be applicable only in select "hotspot" areas due to coverage limitation. For the New T-Mobile case, the use of 5G millimeter wave infrastructure may not be as urgent since it has significantly more sub-6GHz spectrum to rely upon for mobile broadband. The 5G millimeter wave infrastructure may be reserved for other applications.

Based on our modeling of New T-Mobile's network investment choices, including availability, maturity, and timing of certain technology and spectrum options, the following network capacity "map" is forecasted. In the near term, we expect New T-Mobile to deploy CBRS and LAA small cells to increase network capacity in demanding "hotspot" locations. In mid-term, 5G massive MIMO on the 2.5 GHz and C-band may play a vital role in expanding capacity broadly.



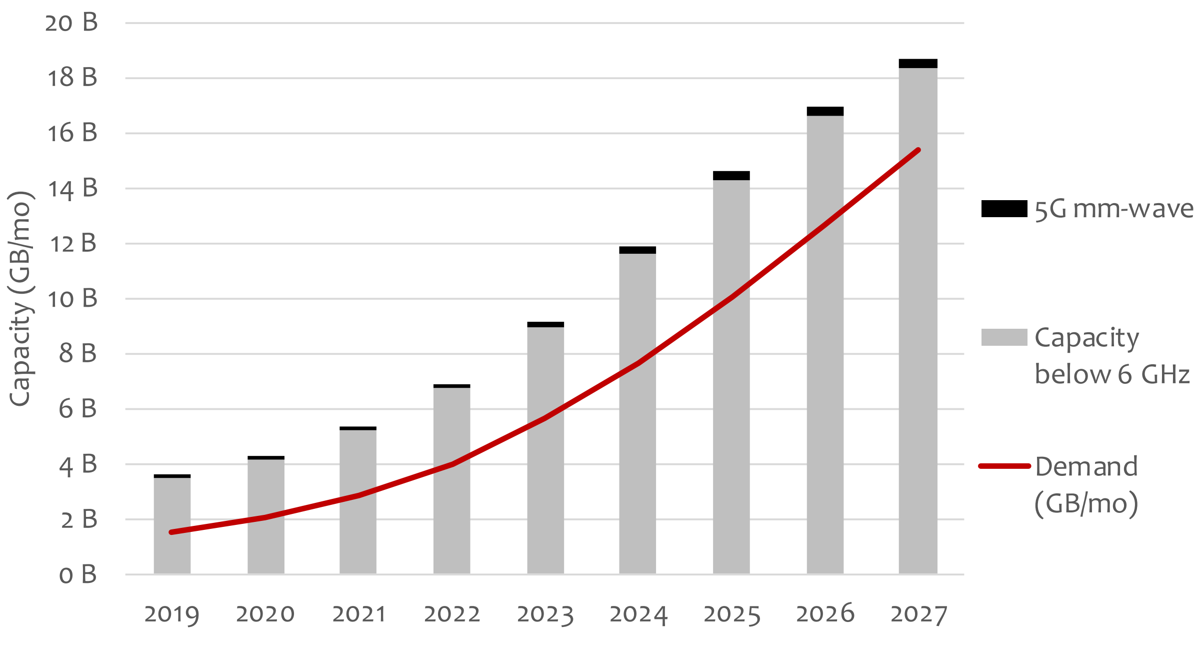
Source: Mobile Experts

Chart 18. Network Capacity by Technology and Spectrum for "New T-Mobile"

NEW T-MOBILE NETWORK SUPPLY VS. DEMAND – AGGREGATE VIEW

Based on the demand trajectory of the operator's subscriber base, which we estimate to be around 40% yearly growth, our model suggests that the network capacity based on sub-6GHz spectrum can readily handle the mobile broadband demand. Despite higher-than-average mobile data usage per subscriber, New T-Mobile has a lot more sub-3GHz spectrum at its disposal than Verizon or AT&T for example. With a full breadth of low

(600-850 MHz), mid (1.9-2.5 GHz and 3.5-4.2 GHz from pending C-band auctions), and high-band (28 and 39 GHz) spectrum, the company has a lot more optionality to expand network capacity without having to rely heavily on the millimeter wave spectrum. With more favorable mid-band spectrum on hand, Mobile Experts forecasts that New T-Mobile will selectively deploy 5G millimeter infrastructure for new applications that require very high-capacity throughput – perhaps in fixed wireless application similar to Verizon's 5G Home service for example. However, we do not expect this to happen in the near term as the company will be busy planning customer migration and integrating some aspects of Sprint's legacy network assets.



Source: Mobile Experts

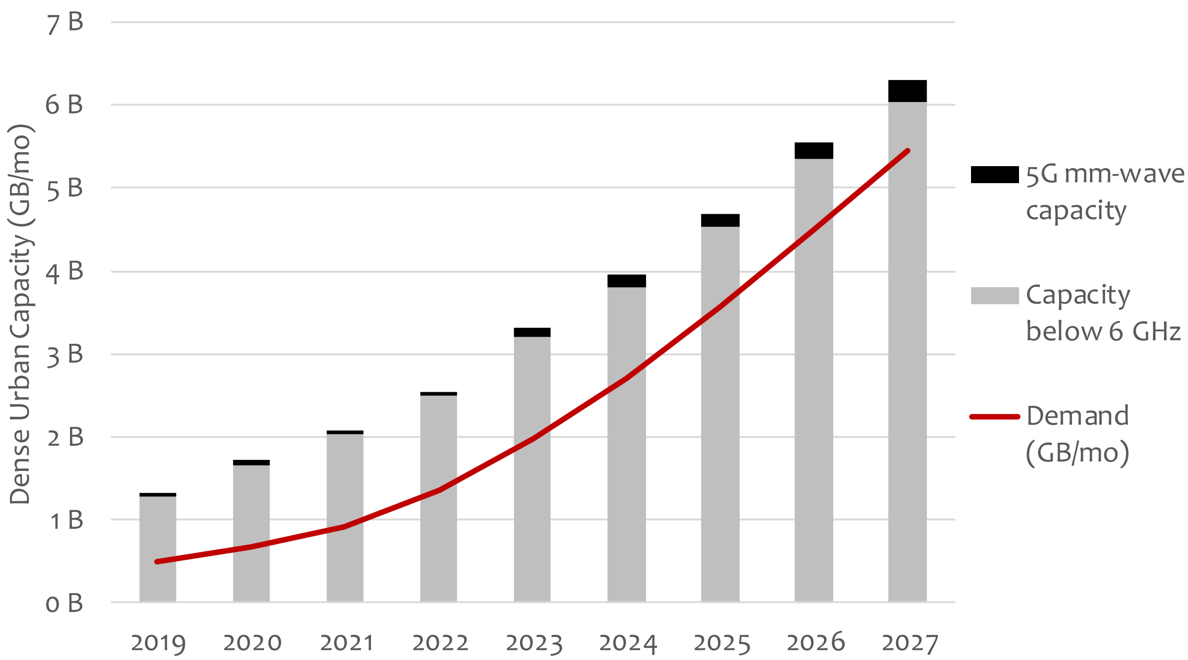
Chart 19. Mobile Network Supply and Demand of "New T-Mobile"

NEW T-MOBILE NETWORK SUPPLY VS. DEMAND – MORPHOLOGICAL VIEW

To understand where network investments will be made requires us to take a closer look at where the mobile data demand is the greatest. Based on our view of the US morphology in terms of population coverage and macro site distribution (see Appendix at the end of the report), we have identified the following view of the network demand vs. (projected) capacity supply that will be invested by New T-Mobile – assuming that the operator maintains its market share during the forecast period over the next 9 years.

Dense Urban

In our "Dense Urban" model of New T-Mobile, despite higher-than-average mobile data usage per subscriber, our model suggests that New T-Mobile will be able to handily serve the rising mobile data demand solely on sub-6GHz spectrum. To address new applications that require targeted, high-capacity links, our model includes adding few 5G millimeter wave small cells in select areas.

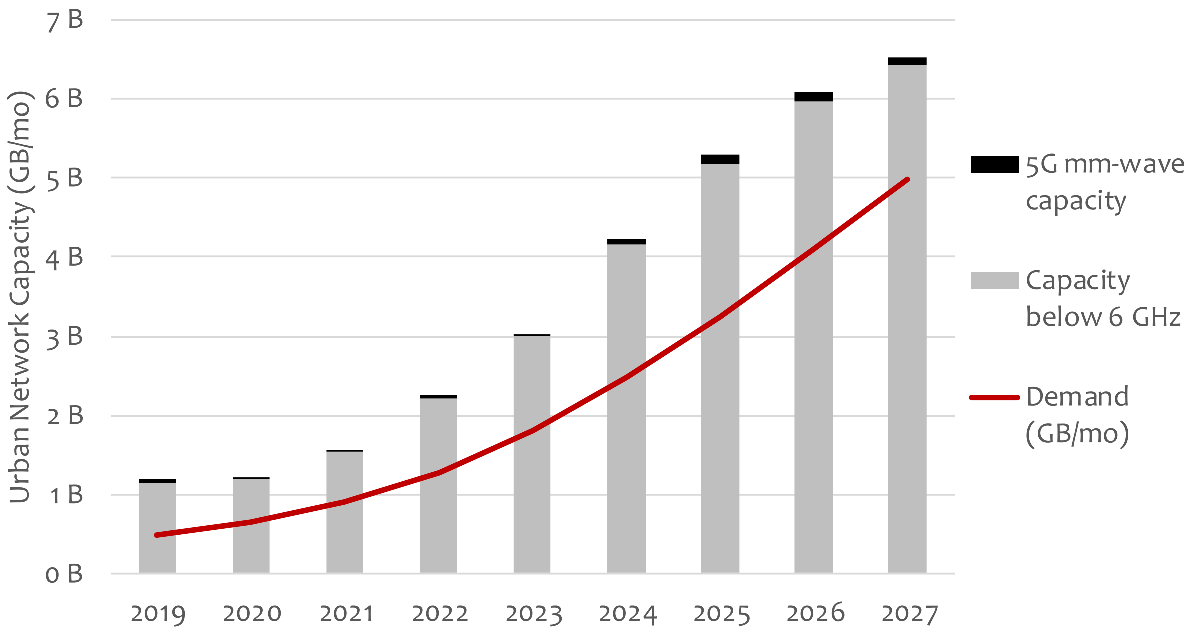


Source: Mobile Experts

Chart 20. Dense Urban Mobile Network Supply vs. Demand of "New T-Mobile"

Urban

Our "Urban" model is based on slightly lower mobile data usage per user as compared to the "Dense Urban" case. It should be noted that our model assumes that New T-Mobile's subscriber base are higher data users than Verizon or AT&T subscribers. While the New T-Mobile's subscribers are, on average, consume 40% more data than the leading operators in the near term, we expect their behaviors mirror those of Verizon or AT&T subscribers over the long term.



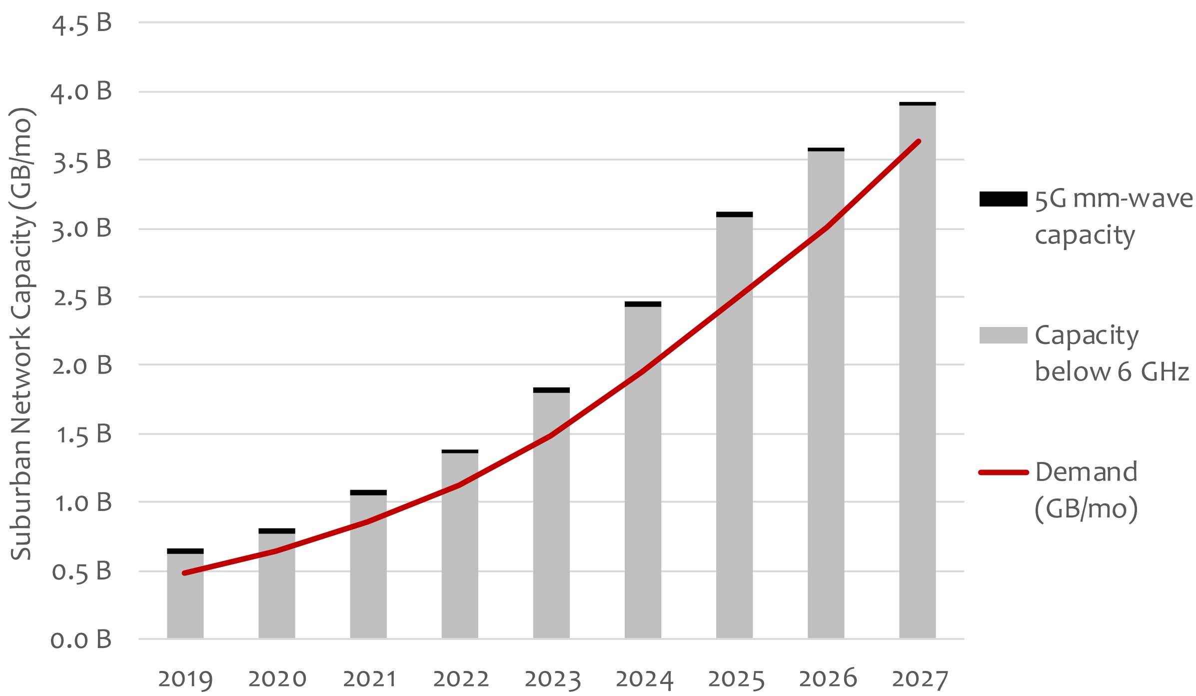
Source: Mobile Experts

Chart 21. Urban Mobile Network Supply vs. Demand of "New T-Mobile"

Again, the 5G millimeter wave network capacity is expected to be deployed for new business opportunities. Our modeling assumes that New T-Mobile will ramp up the C-band (3.7-4.2 GHz) deployment via 5G (64T) base stations similar to Verizon and AT&T.

Suburban

Our "Suburban" model indicates that New T-Mobile will have enough network capacity via sub-6GHz spectrum use during our forecast period. This projection also includes the use of unlicensed and shared spectrum via LAA and CBRS. Again, our modeling assumes that New T-Mobile will ramp up the C-band (3.7-4.2 GHz) deployment via 5G (64T) base stations starting 2021 since it is expected to provide a broad and deep coverage and capacity solution with possibly 100 MHz of channel bandwidth available to deploy in concert with massive MIMO to provide very high spectral efficiency. While we have assumed the use of both 2.5 GHz and 3.7 GHz C-band, the company may opt for 3.7 GHz C-band for the bulk of 5G (64T) base station deployment and leverage 2.5 GHz for other use.



Source: Mobile Experts

Chart 22. Suburban Mobile Network Supply vs. Demand of "New T-Mobile"

Rural

Our "Rural" model indicates that New T-Mobile can meet the projected mobile data demand with available sub-6GHz spectrum including unlicensed spectrum use via LAA and shared spectrum via CBRS. It should be noted that our model includes deployment of the C-band (3.7-4.2 GHz) via 5G (64T) base stations starting 2023 with more moderate ramp than the "Suburban" case since the aggregate demand is expected to be lower than other areas.

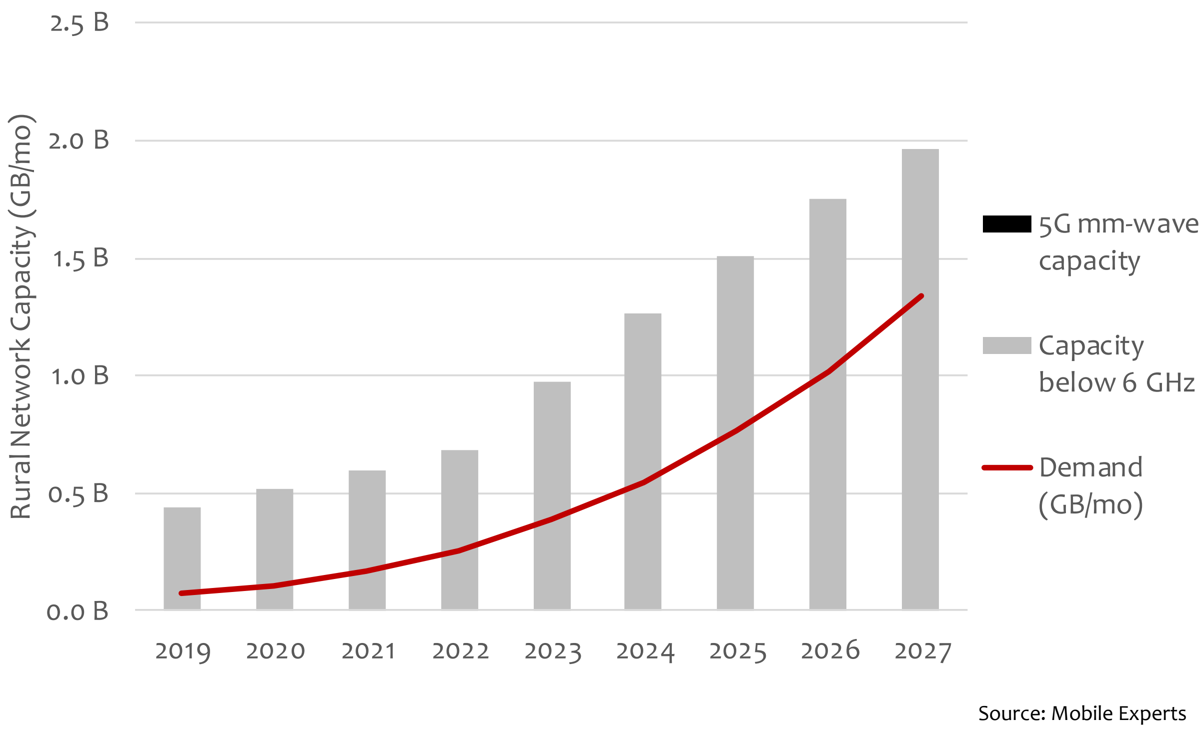


Chart 23. Rural Mobile Network Supply vs. Demand of "New T-Mobile"

VALUE OF 5G INVESTMENTS BY NEW T-MOBILE (FINANCIAL VIEW)

A key premise of our LTE/5G investment model for New T-Mobile is that it will make network investment to facilitate projected mobile network demand. Based on the prospect for moderate growth in service revenue, we have modeled a high-level operating cash flow based on our view of the network CAPEX and OPEX that are needed to generate network capacity to meet the growing mobile network demand as delineated in the various "supply vs. demand" figures noted previously. (Please refer to the MEXP-5GBB-18-BC spreadsheet for detailed figures.)

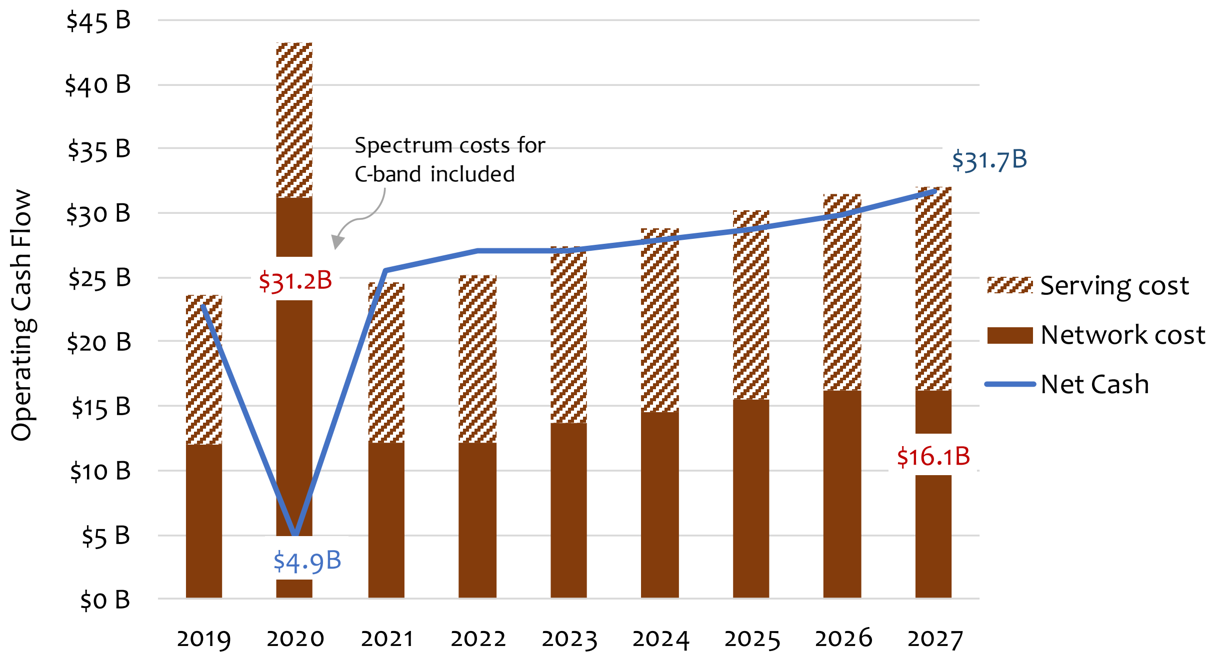
The following assumptions about network demand and cost estimates are applied in our 5G mobile broadband model:

Parameter	Value	Notes
mobile traffic demand per user	14-21 GB per month (in 2019)	The year 0 (2019) estimate based on Ericsson Mobility Report showing average smartphone data usage of 12 GB/month in 2019. Assume that T-Mobile and Sprint subscribers are heavy data users (40% higher than Verizon or AT&T). Assume that per-subscriber data usage resemble those of Verizon and AT&T over time as the subscriber mix becomes blended in a consolidated "three-player" market.
No. of subscribers	30% market share	New T-Mobile will have about 30% market share. Assume that the market share will be maintained during the forecast period except for the Rural case, where the company will grow its share from 10% in 2019 to 25% by 2027.
Cost to serve	25% of service revenue	Costs related to customer service including SG&A is assumed to be ~25% of service revenue (based on historical financial performance of top 2 US MNOs)
ARPU trend	1% annual increase (assuming continual network investment)	Assume that the mobile market will maintain "bounded" competition with rational pricing to maintain a gradual increase in service revenue.
Macro sites	85,000 (in year 0)	According to T-Mobile, it plans to decommission some sites and consolidate towards 85,000 macro sites
Small Cells	50,000 (in year 0)	According to T-Mobile investor presentation

Source: Mobile Experts

Figure 8. 5G Mobile Broadband (New T-Mobile) Cost Modeling Assumptions

Our model assumes that the mobile service revenue is the primary source of revenue and does not account for equipment revenue (from device installment plans for example), or service revenue associated with connected devices in calculating the operating cash flow. The significant network cost increase in the year 2020 again reflects the spectrum cost for the C-band (3.7-4.2 GHz). While the spectrum costs associated with CBRS PAL license and the millimeter wave spectrum are factored in the year 2019 network costs, they are relatively small -- a total cumulative cost estimate of ~$2B for a nationwide footprint. In comparison, Mobile Experts estimates that roughly 10x that amount for the C-band licenses for a nationwide footprint.



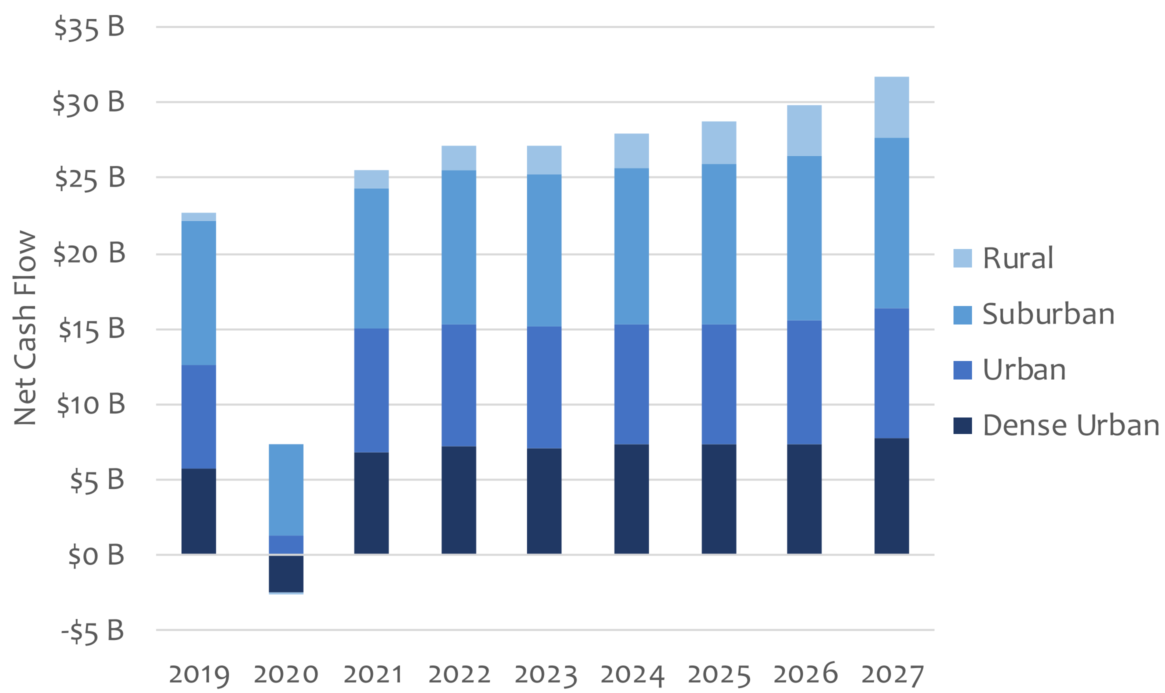
Source: Mobile Experts

Chart 24. Operating Cash Flow of "New T-Mobile"

It should be carefully noted that in our simplified cash flow analysis, the cost of equipment associated with user devices like smartphones is not factored in to provide a simple "network investment vs. service revenue" view.

The Net Cash Flow as shown in the previous figure can be segmented into the different morphological view. While the net cash flows across Dense Urban, Urban, Suburban, and Rural do not defer much except for the year 2020 due to a very high cost of the C-band spectrum licenses[8], the negative network cost impact is heavily skewed towards the Dense Urban case since spectrum cost tends to be significantly more expensive in dense urban than rural markets. In addition, our model illustrates that the negative net cash flow in 2020 also impacts in the Rural case due to relatively low subscriber penetration that the company has in this region (11% compared to over 35% estimated for Verizon). Overall, the net cash flow shows growing trend based on growing service revenue trend forecasted.

[8] While our modeling assumes the C-band spectrum auction to take place in 2020, it may get postponed depending on the series of CBRS PAL and millimeter wave auctions that are expected in the next few years.



Source: Mobile Experts

Chart 25. Net Cash Flow by Morphology of "New T-Mobile"

New T-Mobile's 5G Business Case Summary

For New T-Mobile with relatively robust spectrum holdings, having robust network capacity and growing coverage is key to expanding its market share. Based on our modeling of projected LTE and 5G investments, the 5G investment on robust holdings in the mid-band spectrum including 2.5 GHz and soon-to-be-auctioned 3.7 GHz C-band provides ample network capacity to serve the growing demand.

While a high-level aggregate view of our model (Chart 19. Mobile Network Supply and Demand of "New T-Mobile") across the different urban morphology suggests that the need for 5G millimeter wave infrastructure deployment is not apparent for New T-Mobile, we expect the company to selectively invest in 5G millimeter wave infrastructure to take advantage for mobile broadband if necessary. We expect New T-Mobile to primarily focus on densification (at Macro level) and small cells to increase network capacity along with 5G massive MIMO to significantly increase spectral efficiency at macro sites.

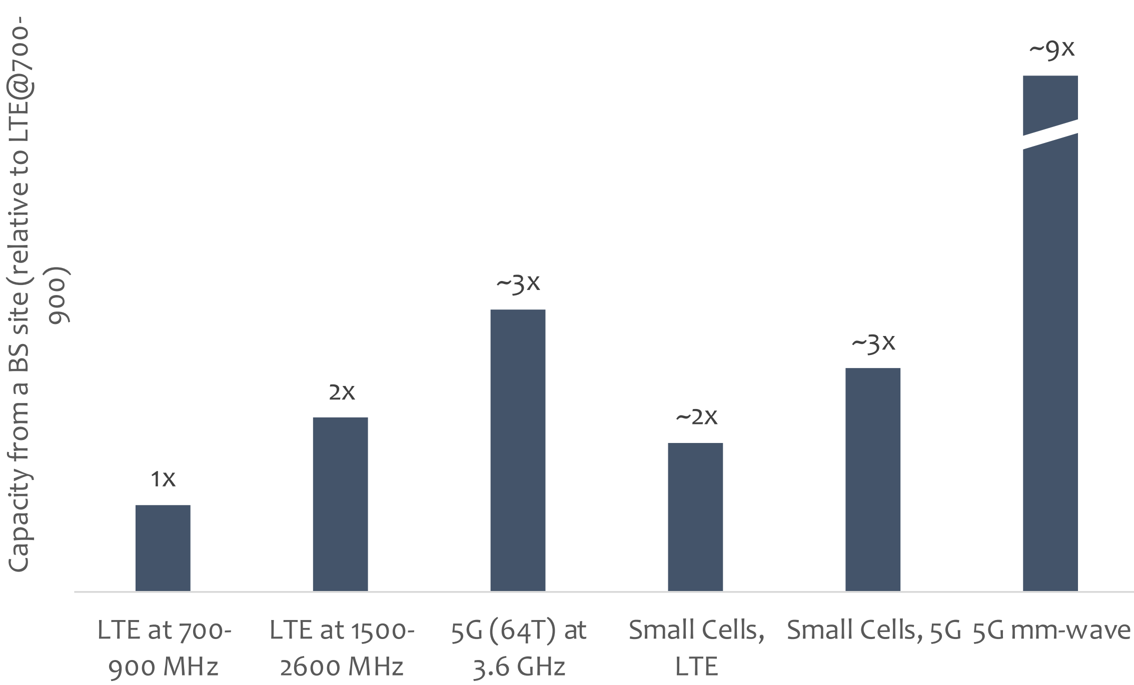
In summary, 5G business case for New T-Mobile mainly relies on 5G massive MIMO investment on mid-band (2.5 – 4 GHz) spectrum to generate the bulk of network capacity it needs to serve mobile broadband demand. Making 5G investment on the millimeter wave is not as urgent for New T-Mobile as it may be for Verizon or AT&T. While maintaining the network supremacy in terms of performance, quality, and cost-competitiveness is critical, New T-Mobile has enough mid-band to deepen network capacity more broadly than with the millimeter wave spectrum.

6. Business Case 5: 5G for Mobile Broadband (European Tier-One)

The fifth and final 5G use case explored in this report is the application of leveraging 5G to primarily serve mobile broadband subscribers. A key premise of this use case is that a European tier-one operator is motivated to leverage more efficient 5G technologies including massive MIMO and the additional spectrum in the mid-band (3.6 GHz) and millimeter wave spectrum to increase network capacity to keep ahead of the rising traffic demand. Based on the lower "cost per GB" unit economics of 5G, the operator is motivated to deploy 5G infrastructure to drive down the unit cost of delivering gigabyte lower while expanding the network capacity. In addition, the operator will be looking to leverage new capabilities of 5G (i.e., low latency and massive connections) to target industrial applications such as smart factory.

Network Capacity Expansion with 5G (and LTE)

Based on the number of macro sites (~31,000) and estimated number of small cells (5,000) in year 2019, total spectrum available for deployment, and the operator's estimated monthly utilization of base stations, we surmise that the European tier-one operator can generate different levels of network capacity as shown below. It should be noted that the amount of network capacity that a particular base station (BS) site can generate depends on technology choice (e.g., LTE or 5G, massive MIMO configuration, etc.) and amount of spectrum deployed at that site.



Source: Mobile Experts

Chart 26. European Tier-1 operator's technology/spectrum choices to increase capacity

For example, 5G base station leveraging 64T64R massive MIMO on 80MHz of 3.7 GHz C-band can produce over three times more "GB/month" capacity than LTE (4x4) base station utilizing 70 MHz of total spectrum across 700-800 MHz. The resultant capacity gain is primarily driven by a higher spectral efficiency of massive MIMO antenna gains. While the capacity gain from a 5G millimeter wave BS is much higher, we believe this will be applicable only in select "hotspot" locations as coverage limitation of such system will limit its widespread application for mobile broadband for the European operator since its mobile traffic demand is much lower than the peers in the United States.

Based on our modeling of the European operator's network investment choices, including availability, maturity, and timing of certain technology and spectrum options, the following network capacity "map" is derived. In the near term, we expect the operator to leverage small cells to increase network capacity in demanding "hotspot" locations. In mid-term, 5G massive MIMO on the 3.6 GHz C-band will play a vital role in expanding capacity more broadly. Lastly, we expect the operator to opportunistically use the 5G millimeter wave infrastructure in hotspot traffic offload and new applications such as fixed wireless access.

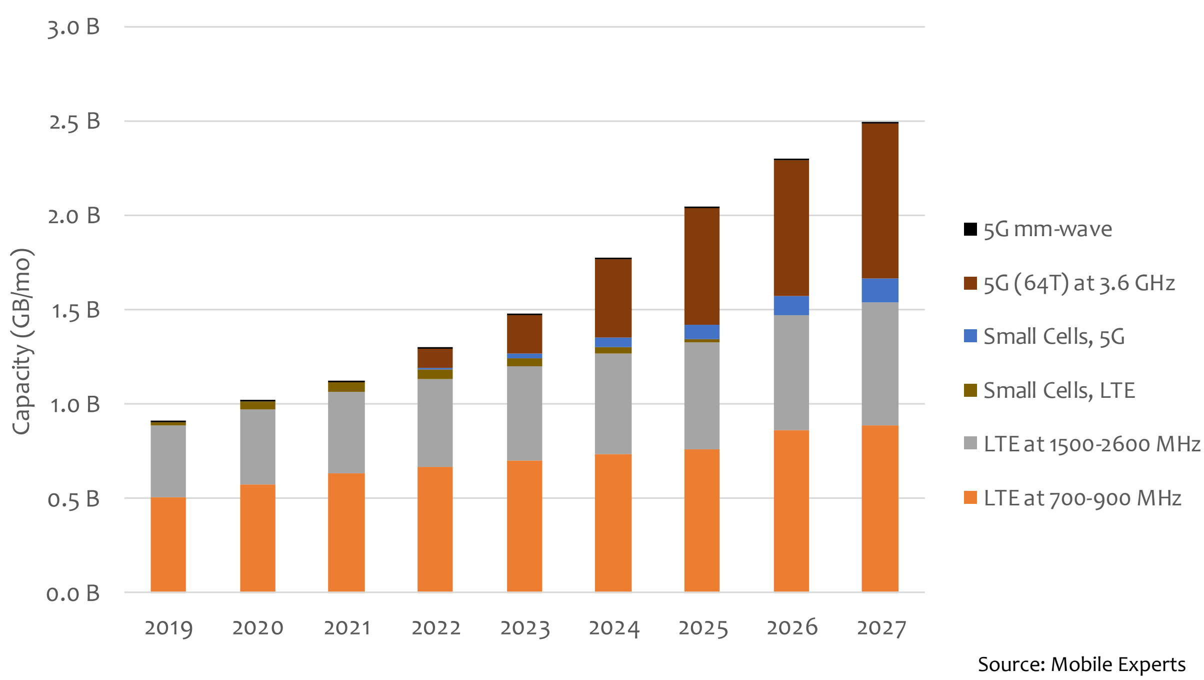
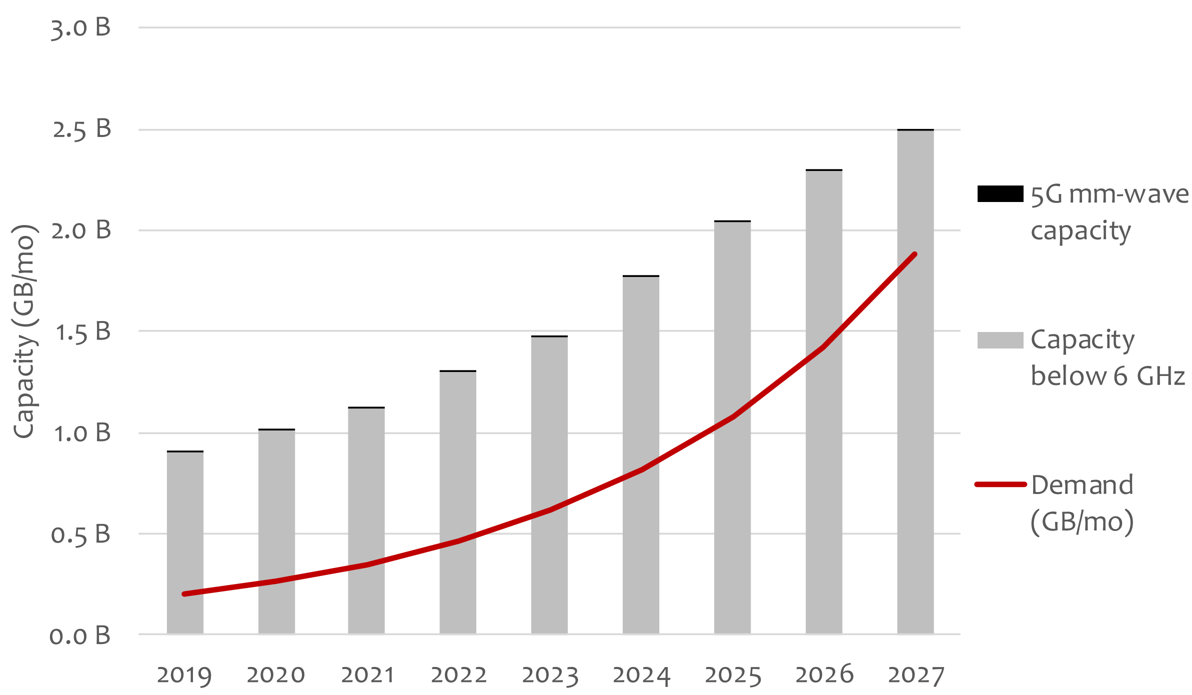


Chart 27. Network Capacity by Technology/Spectrum Choice of a European Operator

EUROPEAN TIER-ONE MOBILE NETWORK SUPPLY VS. DEMAND

Based on the demand trajectory of the operator's subscriber base, which we estimate to be somewhere around 30% yearly growth, our model suggests that the network capacity based on sub-6GHz spectrum with a combination of LTE and 5G will be plentiful to handle the projected demand load.



Source: Mobile Experts

Chart 28. Mobile Network Supply and Demand of a Leading European Operator

VALUE OF 5G INVESTMENTS BY EUROPEAN TIER-ONE OPERATOR (FINANCIAL VIEW)

The following assumptions about network demand and cost estimates are applied in our 5G mobile broadband model for the European Tier-one operator:

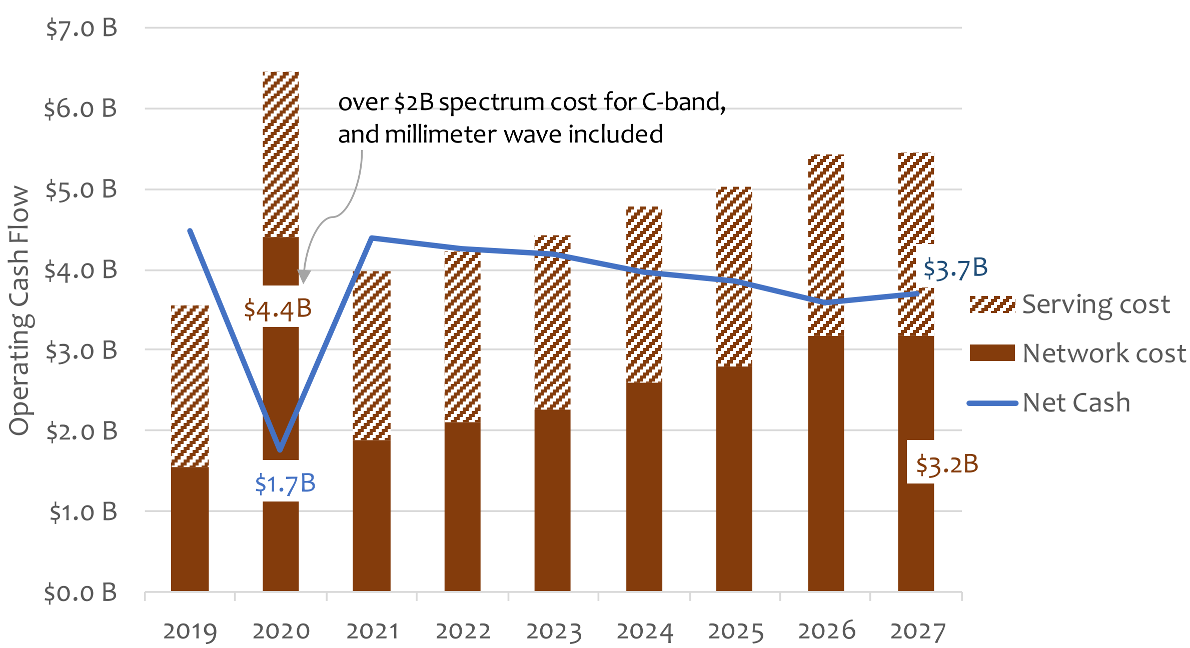
Parameter	Value	Notes
mobile traffic demand per user	7 GB per month (in 2019) growing at 30% CAGR	The year 0 (2019) estimate based on Ericsson Mobility Report showing average smartphone data usage of 7 GB/month in 2019 for western Europe.
No. of subscribers	35% market share of ~80M mobile subscribership	Market share figure for Deutsche Telekom. Assume that the market share will be maintained during the forecast period.

Cost to serve	25% of service revenue	Costs related to customer service including SG&A is assumed to be ~25% of service revenue
ARPU trend	~$23	Assume that the market will maintain "bounded" competition with steady service revenue trend.
Macro sites	31,000 (in year 0)	Based on Deutsche Telekom 2018 investor presentation
Small Cells	5,000 (in year 0)	Mobile Experts estimate

Source: Mobile Experts

Figure 9. 5G Mobile Broadband (European Tier-One) Cost Modeling Assumptions

Based on the prospect for moderate service revenue growth, we have modeled a high-level operating cash flow based on our view of the network CAPEX and OPEX that are needed to generate network capacity to meet the growing mobile traffic demand as delineated in the "supply vs. demand" figure shown above. (Please refer to the MEXP-5GBB-18-BC spreadsheet for detailed figures.) The operating cash flow model assumes that the service revenue is the primary source of revenue excluding other revenue sources like device equipment sales or connected IoT devices.



Source: Mobile Experts

Chart 29. Operating Cash Flow of a Leading European Mobile Operator

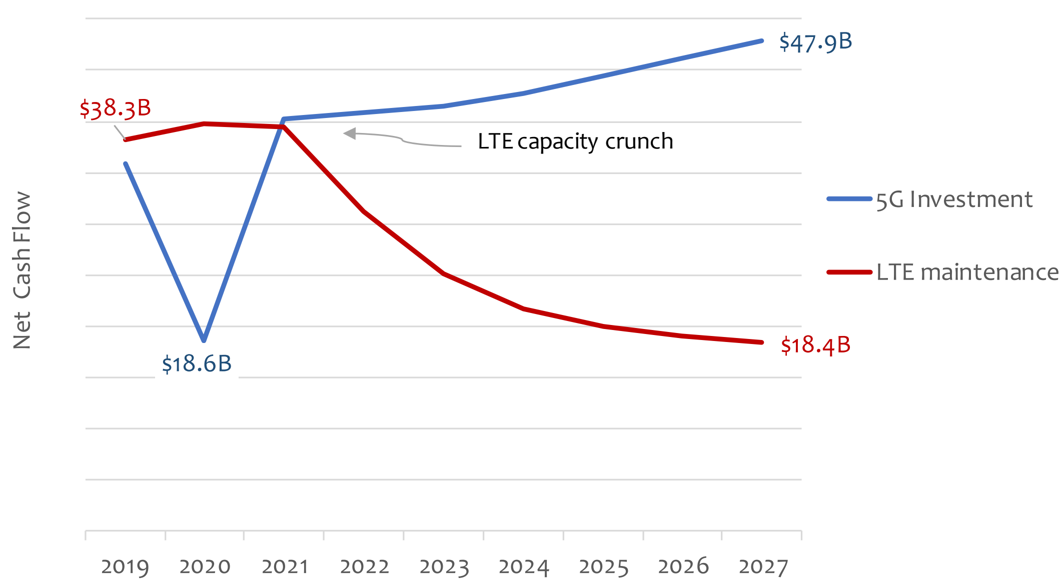
The significant network cost increase in year 2020 reflects the license costs for the C-band (3.6-3.8 GHz) and millimeter wave spectrum, totaling about $2.5B. It is clear that the European tier-one operator can maintain steady net cash flow operation, except for periodic spectrum investments that brings down net cash, while meeting the growing traffic demand through LTE and 5G investments especially leveraging the massive MIMO gains to drive down the unit cost of delivering a GB of data to users.

EUROPEAN TIER-ONE OPERATOR'S 5G BUSINESS CASE SUMMARY

For the leading European mobile operator with significantly lower mobile traffic demand than the US operators, it can comfortably handle the demand load without aggressive network investments. For the European tier-one operator, 5G business case is all about leveraging the lower unit cost of 5G (more C-band spectrum and higher spectral efficiency through massive MIMO antennas) to make its network even more competitive. Meanwhile, the new 5G capabilities such as lower latency and massive IoT enable new revenue-generating opportunities for the operator.

7. Conclusions

The operator motivation for 5G investment varies by operators and regions. For operators with limited spectrum holdings and growing mobile data demand, 5G investment is warranted and urgently needed to lower the unit cost of delivering mobile data. Maintaining current LTE network to meet the growing data demand is simply not enough. Network capacity "crunch" will eventually lead to customer churn and revenue decline. Maintaining cost efficiency is paramount for the mobile operators.



Note: A leading U.S. operator's operating cash flow projected based on revenue and cost outlook

Source: Mobile Experts

Chart 30. 5G investment is needed for future growth

For others, 5G investment brings opportunity to leverage massive MIMO on wider channel bandwidths in the C-band to broadly expand the network capacity. Others, the millimeter wave spectrum offers very high-capacity network options to increase capacity in select hotspot areas for fixed wireless or mobile broadband applications. In all cases, the new capabilities including enhanced mobile broadband, massive IoT, and low-latency critical communication features of 5G expand the operator opportunities to lower the network transport cost and address new business opportunities in fixed wireless, enterprise networking, and industrial IoT applications to name a few. These multi-faceted opportunities will likely drive the operators to adopt 5G more aggressively.

8. Appendix: U.S. Morphology

For the business case study of the mobile broadband demand vs. supply view of the US operators, we have defined the following categories for the urban morphology in the United States.

	Dense Urban	Urban	Suburban	Rural
Population Density (pop/ km^2)	12,000 or greater	3,000 – 12,000	200 – 3,000	200 or less
Land mass (km^2)	~10,000	~30,000	~200,000	~9M
% of Population	6%	25%	51%	18%
% of Macro Sites	20%	25%	25%	35%

Source: US Census, Mobile Experts

Figure 10. U.S. Morphology